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Since the end of the Cold War, the United States has wrestled with how rational deterrence applies to non-state actors in today's complex security environment. Fuzzy logic's themes of flexibility, adaptability, and ambiguity lay the foundation for applying fuzzy logic to non-state actor deterrence. Because fuzzy logic represents real-world human interactions—whether nation-state versus nation-state or nation-state versus non-state actor, applying fuzzy logic and fuzzy cognitive map concepts to non-state actor deterrence presents strategists with effective approaches to enhance homeland security and establishes new models for non-state actor deterrence.

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FUZZY DETERRENCE

by

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A paper submitted to the Faculty of the Joint Advanced Warfighting School in partial satisfaction of the requirements of a Master of Science Degree in Joint Campaign Planning and Strategy. The contents of this paper reflect my personal views and are not necessarily endorsed by the Joint Forces Staff College or the Department of Defense.

This paper is entirely my own work except as documented in footnotes.

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ABSTRACT

Since the end of the Cold War and the September 11, 2001 attacks, the United States has wrestled with how rational deterrence applies to non-state actors in today's complex security environment. Fuzzy logic can serve as a framework for modeling deterrence theory as it applies to non-state actors. The fuzzy logic themes of flexibility, adaptability, and ambiguity lay the foundation for applying fuzzy logic to non-state actor deterrence. Fuzzy logic is a valid approach in 21st century deterrence because it represents real-world human interactions—whether nation-state versus nation-state or nation-state versus non-state actor. Applying fuzzy logic and fuzzy cognitive map concepts to non-state actor deterrence presents strategists with an effective approach to enhance homeland security and establishes a new model for non-state actor deterrence.

To Anne, Katie Rose, and Brooke

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INTRODUCTION

Vagueness is no more to be done away with in the world of logic than friction in mechanics.

—Charles Sanders Peirce[1]

Rational deterrence theory rests on the foundation that deterring threats is possible by doing the following: first, clearly defines the unacceptable behavior; second, communicates a commitment to punish violations; third, possesses the means to punish; and fourth, proves its resolve by carrying out the punishment if challenger fails to deter.[2] For nearly half a century, U.S. deterrence assumptions and calculations largely rested on this rational deterrence framework and revolved around comprehending the dynamics, politics, and culture of the Soviet Union.[3] To counter the Soviet threat, the United States built an arsenal supporting the concepts of a survival nuclear force combined with powerful conventional capability.[4] Arguably, this method of deterring conventional nation-states was successful by the single most important measure; no exchange of nuclear weapons between the United States and the Soviet Union.

The strategic environment today marks a shift from a Cold War nation-state focus. Conventional deterrence still plays a vital role in U.S. strategy—particularly for countries like Russia, China, and Iran. However, since the September 11, 2001 attacks,

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[1] Badredine Arfi, "Linguistic Fuzzy-Logic Game Theory," *The Journal of Conflict Resolution* 50, no. 1 (February 2006): 28. This article provides an interesting discussion around how states demonstrate resolve to a challenger.

[2] Gary Goertz and Harvey Starr, *Necessary Conditions: Theory, Methodology, and Applications* (Lanham, Maryland: Rowan & Littlefield Publishers, Inc., 2003), 148. Page 148 lists four requirements for rational deterrence theory.

[3] U.S. Department of Defense, *National Defense Strategy* (Washington D.C.: United States Government, June 2008), 11-12.

[4] Ibid.

the U.S. increasingly finds itself wrestling with how to deter non-state actors. Indeed, today's complex strategic environment encompasses challenges from a variety of adversaries requiring new capabilities and methods than just nuclear weapons.[5] Furthermore, the challenges encapsulated in today's strategic environment lack the benefits of sixty years of intellectual thought and rigor characterized by Cold War nuclear deterrence practices. For example, a 2002 RAND study on deterring terrorism concluded, "After reviewing the issues, we concluded that Cold War deterrence theory was not, in fact, a very good model for our purposes."[6] Challenges represented by non-state actors like terrorist, necessitate a new approach to the problem set of modeling non-state actor deterrence.

To protect U.S. national security interest, strategic decision makers require tools that expand their action space and policy options. However, there is always a tension within the strategic decision-making process between vague and incomplete information and the decision maker's requirement for the clearest picture possible. This tension manifests itself in the complex and ambiguous arena of real-world communications using words, images, and deeds that underpins deterrence theory. How adversaries receive, perceive, process, and react to communication is critical to deterrence success or failure. However, measuring human perception in strategic communication is inherently imprecise, vague, and fuzzy because of the very nature of language.

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[5] U.S. Department of Defense, *National Defense Strategy*, 11-12.

[6] Paul K. Davis and Brian M. Jenkins, *Deterrence and Influence in Counterterrorism* (Santa Monica, CA: Rand Corporation, 2002), 1.

Fortunately, fuzzy logic has recently emerged on the scene. Fuzzy logic sets are mathematical objects used to model vagueness and uncertainties, like those present in language when describing things, concepts, and ideas without sharply defined boundaries. Fuzzy logic theory provides methods for approximate reasoning processes based on uncertain, incomplete, imprecise, or vague information. The success of this methodology has been demonstrated in a wide variety of fields.[7] Fuzzy logic provides decision makers with tools and methods to capture the inherent vagueness, "fuzziness," and imprecise concepts represented by human language.[8] Furthermore, fuzzy logic tools provide methods to reach definite conclusions using ambiguous, vague, uncertain, imprecise, or missing information.[9]

Utilizing fuzzy logic concepts as a framework for modeling vague and ambiguous concepts provides several characteristics that mitigate the challenges to strategic decision makers surrounding the non-state actor deterrence problem. Fuzzy logic methods eschew traditional binary deterrence approaches that focus on all-or-nothing deterrence models. Instead, fuzzy logic expands the strategic decision maker's action space by allowing for degrees of deterrence and cooperation. This thesis argues that fuzzy logic's means of dealing with vague and approximate perceptions provide flexible and adaptable models for deterring non-state actors.

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[7] Hung T. Nguyen and Elbert A. Walker, *A First Course in Fuzzy Logic*, 2nd ed. (Washington, D.C.: Chapman and Hall/CRC, 2000), preface.

[8] Masao Mukaidono, *Fuzzy Logic for Beginners* (River Edge, New Jersey: World Scientific Publishing Co. Pte. Ltd., 2001), 101.

[9] Steven D. Kaehler, "Fuzzy Logic - An Introduction: Part 1," *Encoder: The Newsletter of the Seattle Robotics Society,* http://www.seattlerobotics.org/Encoder/mar98/fuz/fl_part1.html (accessed September 9, 2009).

Fuzzy logic is extremely applicable to open-dynamic systems, like deterrence, for several reasons. First fuzzy logic allows for ambiguity and provides a framework for vagueness that copes with uncertainty in language. Second, fuzzy theory provides new methods of information processing. Third, fuzzy logic enables the representation of language in models with all of its inherent fuzziness and vagueness.[10]

This monograph addresses logic's humble beginnings rooted in the ideas of British philosopher Bertrand Russell, its mathematical formalization by Lotfi Zadeh, and its use today across a wide variety of topics ranging from politics and business-decision models to financial analysis, the social sciences, and even strategic thinking. Next, deterrence as woven throughout relevant joint doctrine and *The National Military Strategy of the United States of America* is discussed to provide a comprehensive understanding of today's deterrence environment.

With a basic understanding of today's complex deterrence environment, the Prisoner's Dilemma problem is examined. The Prisoner's Dilemma is a classic game-theorist deterrence model used as a simplified version of deterrence to understand interactions and develop new perspectives on social problems.[11] A Cold War, all-or-nothing approach to the Prisoner's Dilemma is contrasted with a fuzzy logic approach. The resulting fuzzy Prisoner's Dilemma game is more flexible and representative of real-world human interactions, offering decision makers more policy and action space rather than an all-or-nothing choice.

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[10] Mukaidono, *Fuzzy Logic for Beginners*, 101.

[11] Roger B. Myerson, *Force and Restraint in Strategic Deterrence: A Game-Theorist's Perspective* (Strategic Studies Institute, November 2007), 5-6.

Finally, with the basics of fuzzy logic and deterrence theory in hand, fuzzy cognitive maps are examined. Fuzzy cognitive maps (FCMs) tie facts, things, and processes together with policies, values, and objectives to draw causal pictures or diagrams of complex systems. FCMs of events in politics, history, medicine, and military planning are used to analyze, predict, and understand how complex events might interact and play out.[12]

FCMs provide decision makers four key benefits. First, they are easy, simple, flexible, and powerful tools enabling decision makers to analyze and model the real world. Second, FCMs are dynamic systems that feed on vague, uncertain, and unreliable information. Third, using FCMs as decision-making support tools improves understanding and comprehension. Finally, FCMs are generally quick and easy to acquire from a variety of knowledge sources with varying degrees of expertise and experience. Each of these FCMs represents a worldview, which can be combined into one FCM illustrating how complex events interact and might play out. All the while, fuzzy cognitive maps by the virtue of being fuzzy and not strictly binary allow for vagueness and uncertainty that is crucial in human interactions. Three example FCMs dealing with non-state actors demonstrate fuzzy cognitive mapping's utility as a framework for non-state actor deterrence.

The strategic decision maker's environment is complex for many reasons, including scope, nature of environment, degrees of uncertainty, vagueness, and complexity. According to strategist Harry Yarger, good "strategy is designed to

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[12] Bart Kosko, *Fuzzy Thinking: The New Science of Fuzzy Logic* (New York, New York: Hyperion, 1993), 222.

accommodate, deter, and seek advantages in the realities of degree, probability, and ambiguity—all incident to a complex chaotic system."[13] Fuzzy logic accommodates and captures the uncertainty, ambiguity, and vagaries of the strategic environment. By avoiding strict all-or-nothing approaches, fuzzy logic reveals more options and policy possibilities to the deterrence decision maker.

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[13] Harry R. Yarger, *Strategic Theory for the 21st Century: The Little Book on Big Strategy* (Washington D.C.: Strategic Studies Institute U. S. Army War College, 2006), 43.

CHAPTER 1

WHAT IS DETERRENCE?

Everything is vague to a degree you do not realize until you have tried to make it precise.
—Bertrand Russell[1]

Deterrence in its simplest form involves two actors, a defender and an aggressor. The defender seeks to either prevent the aggressor from taking hostile action or influence the aggressor to adopt a non-threatening poster. Defenders usually accomplish deterrence by conveying to the aggressor that the decision to refrain from hostile acts is less costly to the aggressor than any other decision. The defender's threats generally are in the form of punishment to the aggressor or promise of successful denial of the aggressor's goal. It is the aggressor's cost-benefit analysis that ultimately determines deterrence success or failure. If the costs outweigh the benefits, the aggressor refrains from action and deterrence succeeds. If the benefits outweigh the costs, the aggressor continues to challenge the defender and deterrence fails.[2]

Deterrence is strategic decision-making process grounded in the assumed rationality of individuals and groups who are pragmatic, flexible, and seek to minimize risks of serious consequences.[3] According to Gary Goertz and Harvey Starr, deterrence boils down to four basic steps. First, a defender must clearly define the unacceptable behavior of the aggressor. Second, the defender communicates a commitment to punish

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[1] Arfi, "Linguistic Fuzzy-Logic Game Theory," 28. Excellent discussion on how nation-states demonstrate resolve to a challenger.

[2] Elli Lieberman, "The Rational Deterrence Theory Debate: Is the Dependent Variable Elusive?" *Security Studies* 3, no. 3 (Spring 1994): 385.

[3] Patrick Morgan, *Deterrence: A Conceptual Analysis,* 2nd ed. (Beverly Hills, CA: Sage Publications, Inc., 1983), 15-16.

the aggressor's violations. Third, the defender must possess the means to punish the aggressor for violations. Fourth, the defender must prove resolve by carrying out the punishment if deterrence fails.[4] A closer look at these four steps reveals that, at its heart, deterrence involves manipulating behavior by clearly communicating the threat of harm.

Deterrence theorist, Elli Liebermann supports Goertz and Starr's approach to deterrence. Liebermann sought to understand the dynamics behind why states deter by examining the strategic decision-making process between Egypt and Israel from 1948 to 1977. He concludes that "leaders of states challenge deterrence or go to war when there are uncertainties about the defender's capability or will, but once the defender reduces these uncertainties by creating a reputation for capability and will, deterrence stability is created even if political pressures to challenge deterrence continue to exist."[5] Liebermann's conclusions, especially that deterrence prevails despite political pressures to the contrary, reinforce deterrence's basis in rationality and the pragmatic decision making of individuals and groups.

For nearly half a century, the U.S. approached deterrence from the single-minded approach of deterring the Soviet Union. U.S. deterrence assumptions and calculations largely rested on comprehending the dynamics, politics, and culture of the Soviet Union.[6] These Cold War assumptions and calculations generated deterrence models like Bernard Brodie's mutual assured destruction and President Kennedy's "Flexible Response," which rejected massive retaliatory and instead emphasized nuclear counterforce

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[4] Goertz and Starr, *Necessary Conditions*, 148.

[5] Lieberman, "Rational Deterrence Theory Debate," 384-429.

[6] U.S. Department of Defense, *National Defense Strategy*, 11-12.

targeting.[7] To counter the Soviet threat, the United States built an arsenal based around the concept of a survival nuclear force combined with powerful conventional capability.[8]

The strategic environment today marks a shift from the Cold War focus of deterring single challengers to deterring a range of potential adversaries. That is not to say that conventional deterrence does not still have a place in U.S. strategy; particularly for countries like Russia, China, and Iran. However, to counter today's range of adversaries requires a greater variety of capabilities and methods than just nuclear weapons.[9] Current U.S. documents reflect this need to shift to a broader concept of deterrence.

The *National Security Strategy of the United States of America* states, "The new strategic environment requires new approaches to deterrence and defense. Our deterrence strategy no longer rests primarily on the grim premise of inflicting devastating consequences on potential foes. Both offenses and defenses are necessary to deter state and non-state actors, through denial of the objectives of their attacks and, if necessary, responding with overwhelming force."[10] The document further states the U.S. is "pursuing a future force that will provide tailored deterrence of both state and non-state threats."[11] These statements demonstrate at the highest levels a shift from a Cold War

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[7] Robert J. Art, G. John Ikenberry, Frederick Kagan, Barry Posen, Sarah Sewall, and Vikram J. Singh, *Finding Our Way: Debating American Grand Strategy,* Solarium Strategy Series, edited by Michèle A. Flournoy and Shawn Brimley, (Washington D.C.: Center For A New American Security, 2008), 17.

[8] U.S. Department of Defense, *National Defense Strategy*, 11-12.

[9] Ibid.

[10] U.S. Government, *National Security Strategy of the United States of America*, United States Government, (March 2006), 22.

[11] Ibid., 43.

emphasis on nuclear deterrence and clearly indicate the United States is wrestling with a new strategic paradigm requiring new approaches to deterrence.

Joint Publication 3-40: Combating Weapons of Mass Destruction (CWMD) perhaps provides the best summary of the strategic issues facing deterrence today.

> In the latter half of the 20th century, CWMD strategy was largely based on deterrence of a very small number of nation-states. The threats at the time were characterized by established, effective governments; stringent control and accountability measures for WMD weapons; large conventional militaries with near parity; set geographic areas; substantial economic and industrial bases; and, perhaps most importantly, a relatively clear understanding of adversary motivations and risk calculations. Today's security environment consists of a wide variety of threat actors ranging from state actors, with characteristics similar to earlier threats, to non-state actors, including terrorists, other transnational groups, and even industrial concerns, with vastly different characteristics. These actors may have little to no established government or leadership structure; few controls on weapons or operations; small cells or even no conventional military capability; operate across political and geographic boundaries; no clear economic base that can be held at risk; and differing or even competing agendas, motivations, and objectives.[12]

Two key terms mentioned above are nation-state and non-state actors. The nation-state is a state that derives its political legitimacy by serving as a sovereign entity for a nation. The concept of a nation-state arguably grew out of the 1648 Treaty of Westphalia and the idea that sovereignty is rooted in the principles of territory and the exclusion of external actors from domestic authority structures.[13] From a strategic decision making point of view, for the U.S. nation-states generally present a "relatively clear understanding of adversary motivations and risk calculations."[14]

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[12] U.S. Joint Chiefs of Staff, *Joint Publication 3-40: Combating Weapons of Mass Destruction* (Washington D.C.: United States Government, June 10, 2009), II-1.

[13] Leo Gross, "The Peace of Westphalia," *The American Journal of International Law* 42, no. 1 (January 1948): 20–41.

[14] Ibid.

Non-state actors, on the other hand, have no territorial boundaries or domestic authority structures. They are actors on the international world stage that include terrorists, extremists, nongovernmental organizations, insurgents, organized criminal groups, international businesses, rogue scientists, and even individuals acting independently of any organization.[15] *The National Military Strategy of the United States* describes non-state actors as politically unconstrained "groups that menace stability and security" and indicates non-state actors "may be less susceptible to traditional means of deterrence."[16] The document goes on to characterize the dealings with non-state actors as a "volatile mix of challenges [that] requires new methods of deterrence."[17] Terrorists for example, involve many groups, use a variety of instruments, and are often loose associations with no central command. Deterrence is especially difficult for those who have chosen terrorism as a way of life.[18] They are not a single foe or entity, and no simple theory of deterrence can cover the entire spectrum.[19]

The foundation of deterrence is the assumed rationality of individuals and groups who are pragmatic, flexible, and seek to minimize risks of serious consequences.[20] Repulsive as their actions may be, terrorists are not irrational actors.[21] Three analyses of

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[15] U.S. Joint Chiefs of Staff, *Joint Publication 3-40,* II-2.

[16] U.S. Joint Chiefs of Staff, *National Military Strategy of the United States* (Washington D.C.: Department of Defense, 2004), 5.

[17] Ibid.

[18] Davis and Jenkins, *Deterrence and Influence,* 5.

[19] Ibid., 7.

[20] Morgan, *Deterrence: A Conceptual Analysis,* 15-16.

[21] Davis and Jenkins, *Deterrence and Influence,* 5.

terrorist threats suggest that strategic deterrence decision making is not the sole domain of the nation-state, but is tailorable to non-state actors as well.

A 2002 RAND study *on Deterrence and Influence in Counterterrorism* asserts that even the most "dangerous element in a system may be deflected from one mode of activity to another, or from one set of targets to another."[22] The study suggests nation states should focus on the elements or individuals that support or influence non-state actors that are deterrable. For example, a particular leader may not easily be deterred, but covert state supporters or wealthy donors may be susceptible.

M. Elaine Bunn, a distinguished research fellow at the Instituted for National Strategic Studies, agrees with the RAND study's approach. Her article "Can Deterrence be Tailored?" emphasizes deterrence can be effective against non-state actors.

> Some would say that deterring terrorists is an oxymoron, given the appeal of suicide or "martyrdom" operations for some kinds of terrorists....However, it is also true that even terrorists with suicidal inclinations want to die to accomplish something and that defensive deterrence—that is, denying them the accomplishment, or the "benefits" of their actions—may, over time, be the more effective way to think about deterring terrorists.[23]

Central to the concept of deterring state or non-state actors is communicating the commitment to punish and consummate resolve to carry out that punishment. As Bunn notes, "The clarity and credibility of American messages in the mind of the deterree are critical to tailoring deterrence threats. U.S. policymakers need mechanisms to assess how their words and actions are perceived, how they affect each adversary's deterrence calculations."[24]

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[22] Davis and Jenkins, *Deterrence and Influence*, 22.

[23] M. Elaine Bunn, "Can Deterrence be Tailored?" *Strategic Forum*, no. 225 (2007): 3.

[24] Bunn, "Can Deterrence be Tailored," 1.

The National Institute for Public Policy paper, "Deterrence and Coercion of Non-State Actors: Analysis of Case Studies," also examined whether nation-states can deter non-state actors. The study examined ten conflicts across more than two centuries ranging from less than a year to more than two decades. Additionally, the conflicts spanned the globe including Africa, the Middle East, North America, the Caucasus, and Europe. Overall, the report concluded that many prevalent views of non-state actor deterrence opponents are inaccurate. These commonly held views include:

1. Non-state actors are irrational, so they cannot be deterred.
2. Non-state actors have no territory or state-based assets that can be held at risk, so they cannot be deterred.
3. If non-state actors are deterrable, a universal approach should be easy to develop.

Furthermore, the report found nation-states who successfully deterred non-state actors did not do so through Cold War tactics of holding adversary's high-value assets at risk. Instead, nation-states found non-state actor deterrence often resulted from using a combination of methods tailored to the individual characteristics of a particular non-state actor. Finally, the report presents several key findings, among them that a non-state actor's hostile action is preventable by deterrence measures. Deterrence strategies will vary and there will be cases where deterrent options are not applicable or infeasible for a variety of reasons. Furthermore, there will be times when deterrence only works for some time until the strategic environment changes.[25] Taken as a whole, the report

[25] Keith B. Payne et al, *Deterrence and Coercion of Non-State Actors: Analysis of Case Studies,* (National Institute for Public Policy, Fairfax, October 2008).

stresses the need to shift away from the Cold War, all-or-nothing, approach to a comprehensive one that allows for tailored methods and degrees of deterrence.

What strategists require are approaches to non-state actor deterrence that combine several factors. The first factor is the heart of deterrence: manipulating behavior by clearly communicating the threat of harm to adversaries. The second aspect is that deterrence rests on the assumption that pragmatism and rationality are evident in the decision-making models of both the nation-state and non-state actor. The third variable is today's strategic environment, which represents a shift from the Cold War's focus on major player nuclear deterrence and requires a new approach to strategic decision making. While traditional deterrence models hold true for nation-state actors, the nation-state approach to deterrence is less useful for non-state actor threats. A new approach is required that accounts for the complexity and ambiguity presented in non-state actor deterrence. Fuzzy logic provides that approach.

CHAPTER 2

WHAT IS FUZZY LOGIC?

As complexity rises, precise statements lose meaning and meaningful statements lose precision.

—Lotfi Zadeh[1]

Fuzzy logic is reasoning with vague concepts.

—Bart Kosko[2]

Fuzzy logic has its roots in the ideas of British philosopher and logician Bertrand Russell, who in 1923 published an article entitled "Vagueness." Russell asserted that language is not precise, but vague and vague to a matter of degree.[3] Fuzzy logic is an extension of Russell's concept of vagueness into a mathematical model providing methods to move away from classical logic's strict binary TRUE or FALSE depiction of conditions. Fuzzy logic applies Russell's vague linguistic system variables [e.g. large, hot, tall] over a continuous range of values between 0 and 1. By doing so, fuzzy logic provides a way to view the world as multi-valued shades of grey with degrees of truth and approximation between 1 and 0, rather than absolute values. For example, take a half-full glass of water. In classical logic's TRUE or FALSE thinking, the glass must be either empty or full, 0 or 1. In reality, the glass is more than empty, but less than full. It

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[1] Arfi, "Linguistic Fuzzy-Logic Game Theory," 28.

[2] Bart Kosko, *Fuzzy Future: From Society and Science to Heaven in a Chip* (Westminster, MD: Crown Publishing Group, Inc., 1999), 6.

[3] Bertrand Russell, "Vagueness," *The Australasian Journal of Psychology and Philosophy,* no. 1 (June 1923): 84-92.

is something between 0 and 1. It is both a degree of empty and a degree of full at the same time.[4]

The father of fuzzy logic is Lotfi Zadeh. Zadeh was born in 1921 in Baku, Soviet Azerbaijan. In 1943, he graduated from the University of Teheran with a degree in electrical engineering, immigrated to the United States in 1944, studied at the Massachusetts Institute of Technology, and earned full professorship in 1957. A year later, he joined the facility at the University of California at Berkeley. In 1965, he published his most famous paper, "Fuzzy Sets" in which he worked out a complete mathematical system for fuzzy-set algebra and coined the term fuzzy logic.[5]

Professor Zadeh specifically designed fuzzy-set mathematics to represent the uncertainty and vagueness found in many problems. The theory provides mathematical methods for capturing the uncertainties associated with human cognitive processes. As a result, fuzzy logic approaches to problem solving, in many ways, mimics how a person approaches decisions with vague, uncertain, incomplete, and imprecise information.[6] Three essential fuzzy logic characteristics are: (1) everything is a matter of degree; (2) fuzzy logic is suitable for uncertain or approximate reasoning, especially for systems with difficult mathematical models; and (3) fuzzy logic enables decision making with either incomplete or uncertain information.[7]

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[4] Kosko, *Fuzzy Thinking*, 4-17.

[5] Daniel McNeill and Paul Freiberger, *Fuzzy Logic: The Revolutionary Computer Technology That Is Changing Our World* (New York, New York: Touchstone, 1993), 10–22. Page 15 describes how Lofti Zadeh came up with the entire fuzzy logic framework in three hours after missing a dinner date.

[6] Steven D. Kaehler, "Fuzzy Logic - An Introduction."

[7] Cengiz Kahraman, "Decision-making and Management Applications," *Journal of Enterprise Information Management* 20, no. 2 (2007): 147.

The term “fuzzy” did not sit well with the Western scientific world, which was at the time according to an author familiar with the history of Zadeh’s idea, “throwing ever more math at problems and trying to think and run the business of science with the black-white reasoning that computers and machines used.”[8] Academic institutions scoffed at Zadeh’s fuzzy logic as nothing more than probability in disguise. As a result, neither industry nor government sectors diverted sufficient resource dollars toward the concept.[9]

Although, fuzzy logic concepts and methodologies gained little traction in the United States, Zadeh’s concepts found early adoption in Asian countries that had less cultural and philosophical resistance to the idea of applying fuzzy logic in science and engineering.[10] For instance, the Japanese government assisted in funding two fuzzy research centers: the Laboratory for International Fuzzy Engineering Research (LIFE) and Fuzzy Logic Systems Institute (FLSI). In 1989, the LIFE center alone received $70 million from the Japanese government over five years to study fuzzy logic applications. Fuzzy logic became part of the Japanese people’s daily lexicon; discussed on nightly news programs, as well as by pundits and political figures. While most Japanese applications began in consumer electronics, fuzzy logic applications for manufacturing, banking, and other information systems are gaining ground. By the early 1990s, Japanese firms held over a thousand fuzzy logic-based patents in Japan and Japanese companies

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[8] Kosko, *Fuzzy Thinking*, 20.

[9] Ibid., 10-20. Probability is a mathematical application to explain the odds, between 0 and 1, on how events will unfold. Although fuzzy logic values and probabilities values look similar because both range between 0 and 1, they should not be confused. In general, the probability that a coin toss comes up heads or tails always adds up to one. There is no degree or vagueness, the coin always lands heads or tails. Furthermore, as information increases, probability tends to evaporate. In this case the laws of physics, not chance, determine how the coin lands. Fuzzy logic is not a gamble, wild guess, chance, or randomness. It is a representation of degrees of truth presented in a mathematical model using vaguely defined sets.

[10] Ibid., xvi.

held 30 of the 38 fuzzy logic-based patents granted by the United States during the same period.[11]

As fuzzy logic spread across Europe in the late 1990s, Germany became the European leader in fuzzy logic-based applications related to heavy industry and process control. Currently, fuzzy logic-based process control systems in Germany reduce sway in large industrial cranes, control the temperature in plastic molding machines, and control the power output of a Belgian nuclear reactor.[12]

Today, a Google search on the term "fuzzy logic" returns over 2.5 million hits with topics ranging from politics and business-decision models to financial analysis, the social sciences, and even strategic thinking. In his book, *Strategic Theory for the 21st Century: The Little Book on Big Strategy*, Harry Yarger succinctly describes fuzzy logic:

> Thus if you are asked if a number is a 1 or a 0, it is clearly one or the other. In reality, the world is very much gray. If you are asked if 0.4 is a 1 or a 0, in Western Boolean thinking you must decide which it is and act accordingly. In reality it is more than a 0 and less than a 1, something in between, or gray. Hence, fuzzy logic argues that everything is a matter of degree or multivalence—with three or more options or an infinite spectrum of options instead of the two extremes of true or false. Fuzzy logic advocates argue that, for the sake of simplicity, our culture traded off accuracy—the way the world is in reality— for a black or white answer. Western scientific thought is limited or hindered by this Boolean logic.[13]

Yarger's point of accuracy versus extremes of TRUE or FALSE is readily illustrated in the following two simple examples that depict fuzzy logic's shades of truth, vagueness, and ambiguity.

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[11] Kosko, *Fuzzy Thinking*. Patent data is on page 188-190. The rest of the paragraph is a summary of thoughts located throughout the book.

[12] Kosko, *Fuzzy Future*, 5.

[13] Yarger, *Little Book on Big Strategy*, 43.

The first example uses the idea of intensity with respect to rounds fired in a firefight to illustrate the paradox of the heap argument against traditional logic.[14] Imagine that there is a requirement to classify the intensity of a firefight. Anyone can pick an arbitrary value to represent a firefight's intensity. For example, 1,000 rounds fired represents an intense firefight and zero rounds fired represents no intensity. Now subtract one round. Is the firefight still intense? According to classic Boolean logic, a TRUE (1) or FALSE (0) concept of intensity requires that some specific number of rounds fired indicates either 100 percent intensity or 0 percent intensity. Boolean logic allows no other outcomes but TRUE or FALSE (see Figure 1). Therefore, 999 rounds fired is 0 percent intensity, but add just one round and the firefight becomes 100 percent intense. Clearly, the absolute nature of the Boolean approach fails to capture the imprecise and uncertain nature of capturing intensity during a firefight.

[14] The idea of the paradox of the heap attributed to Eubulides of Miletus. The paradox revolves around a heap of sand containing 1,000,000 grains. Subtracting a single grain of sand from the heap still leaves a heap. Continuing to removing grains of sand one at a time, eventually leads to the conclusion that a heap may be composed of just one grain of sand.

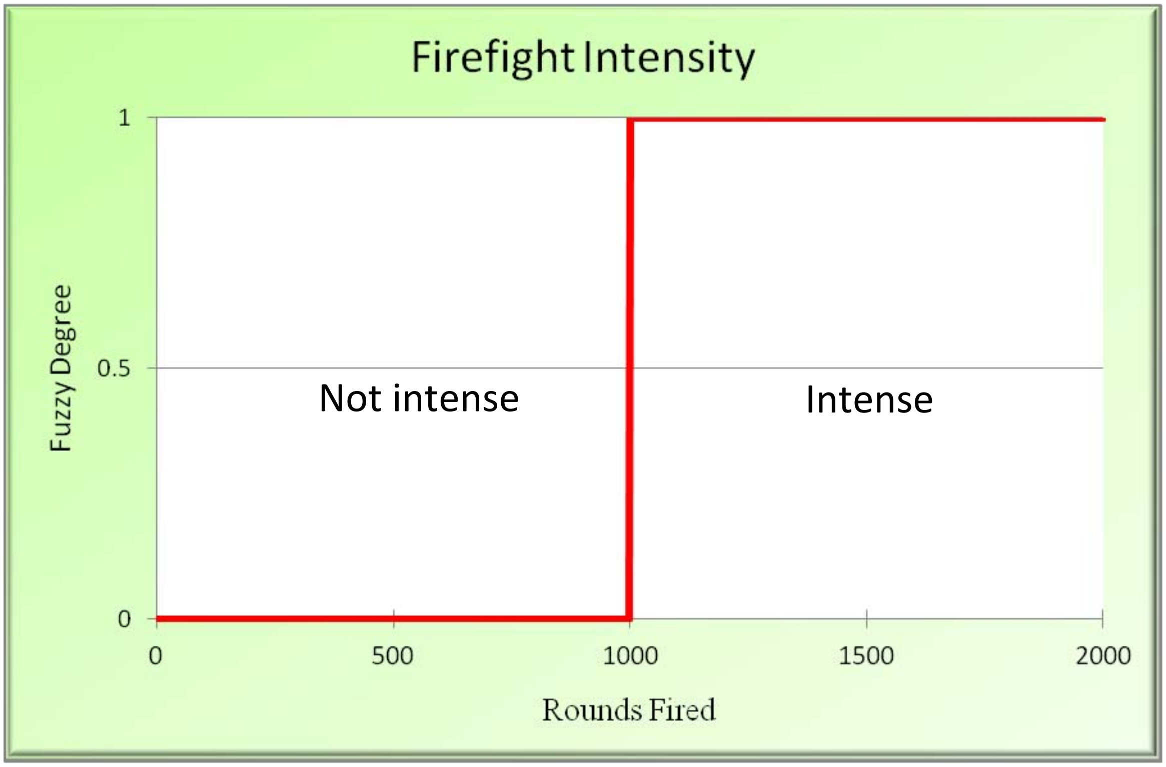

Figure 1. Graphical application of Boolean logic representing the intensity of a firefight.

Fuzzy logic, in contrast, accepts that there are an infinite number of degrees of intensity. Using the same arbitrary range in Figure 1, zero percent intensity is equal to zero rounds fired and 100 percent intensity is greater than or equal to 2,000 rounds fired. Adding rounds fired gradually makes the firefight more intense, but there is no clear delineation marking the point where a firefight shifts from not intense to intense. Figure 2, is a graphical representation revealing a slope where a firefight is more or less intense depending on the number of rounds fired. The utility of fuzzy logic is its ability to represent levels of uncertainty that exists in both simple and complex ideas. Thus, the fuzzy logic graph illustrates the notion of degrees of intensity in a firefight in a way that traditional sharp Boolean logic cannot.

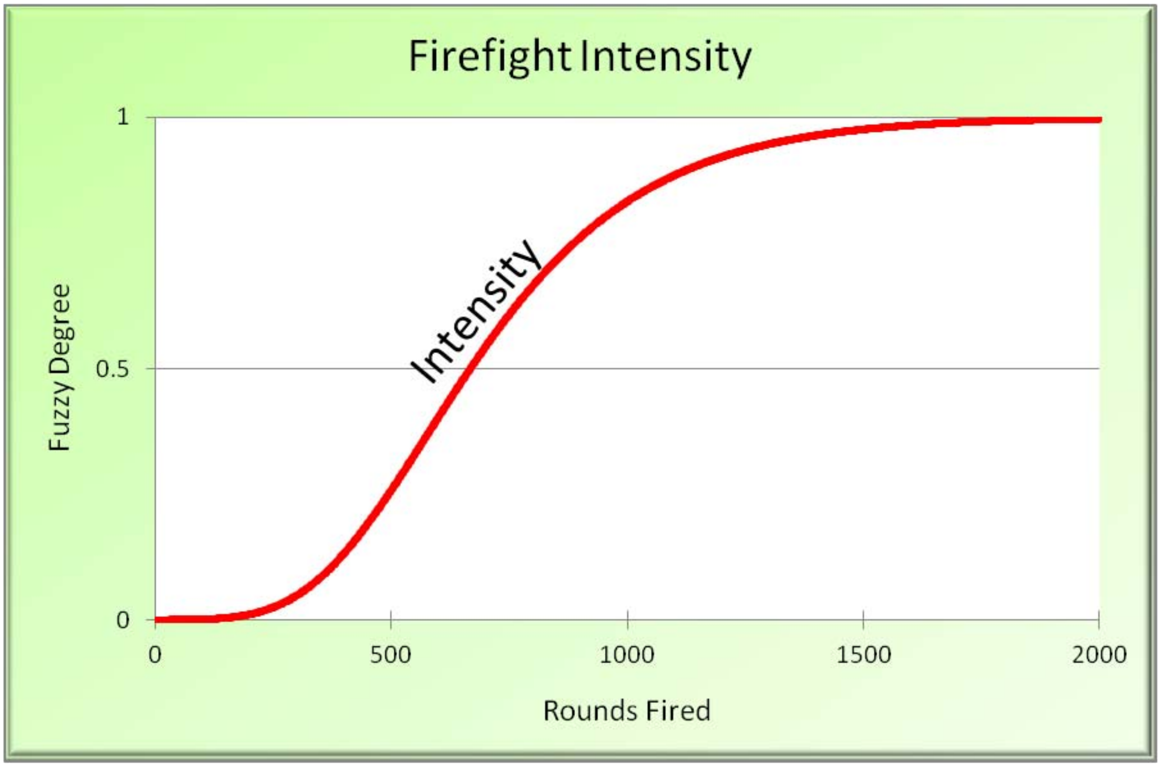

Figure 2. Fuzzy logic representation of firefight intensity with sigmoid slope.

These two examples clearly demonstrate fuzzy logic's ability to handle shades of truth, vagueness, and ambiguity. Yarger's use of fuzzy logic concepts in his strategy book shows how varied fuzzy logic-based applications to problem solving and decision making have become. Yarger stresses the need to turn away from strict Boolean logic approaches and asserts that good strategic decision makers embrace fuzzy logic concepts.

> Westerners, with their unitary outlooks, are culturally at a disadvantage in perceiving the possibilities for the strategic realm, marked by complexity and ambiguity. Western thinking is primarily scientific or Newtonian. To get the rationality of western logic, the reality of the world is expressed in either or terms—it is assumed to be either black or white. The strategic environment is much less objective than Western logic portrays it, often containing more gray than black and white. Good strategists have always recognized this ambiguity and how to think about it.[15]

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[15] Yarger, *Little Book on Big Strategy*, 42.

At the strategic decision-making level, reliance on either/or thinking distorts reality, leads to false assumptions, limits options, obscures complexity, and constrains decision makers.[16] The tools used to model for and influence decision makers must reflect the uncertainty and ambiguity of the way the world works in reality so they can be applied to wider issues of national security and national strategy. After all, strategy like non-state actor deterrence, must live in the real world of grayness and arrive at conclusions based upon vague, ambiguous, imprecise, noisy, missing, or incomplete information.

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[16] Yarger, *Little Book on Big Strategy*, 44.

CHAPTER 3

WHY FUZZY LOGIC?

When the only tool you have is a hammer, everything begins to look like a nail.
—Lofti Zadeh[1]

There is always a tension within the strategic decision-making process between incomplete and uncertain information and decision makers' need for the clearest picture possible. In the realm of deterrence, difficulties implicit in the complex and ambiguous arena of real-world communication exacerbate this tension, especially with respect to addressing non-state actor deterrence. The deterrence strategic environment is rife with inherent uncertainty, chance, and interaction with other nation-states and a variety of non-state actors.[2] From the U.S. perspective, non-state actor deterrence requires a paradigm shift from a Cold War-type focus on nation states as the major players to an increasing focus centered on non-state actors. Unfortunately, the challenges encapsulated in today's strategic environment lack the benefits of sixty years of intellectual thought and rigor characterized by Cold War nuclear deterrence. These challenges necessitate a new approach to the problem set of modeling non-state actor deterrence. Fortunately, fuzzy logic has several key characteristics that mitigate the challenges surrounding the non-state actor deterrence problem.

Fuzzy logic has the ability to capture the inherent vagueness, "fuzziness," and imprecise concepts represented by human language.[3] Fuzzy logic tools provide methods

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[1] McNeill and Freiberger, *Fuzzy Logic*, 174.

[2] Yarger, *Little Book on Big Strategy*, 16.

[3] Mukaidono, *Fuzzy Logic for Beginners*, 101.

to reach definite conclusions using ambiguous, vague, uncertain, imprecise, or missing information.[4] According to Nasser Ghasem-Aghaee and Ören I. Tuncer, who use fuzzy logic for human behavior simulation, fuzzy logic "provides an excellent way to represent and process variables."[5] This ability to represent language is important because language is the foundation for communicating between humans and communicating harmful intent is at the heart of deterrence. As such, language plays a significant role in the strategic decision-making process.

Fuzzy logic's approach to variables supports more accurate modeling for a decision process and is a better representation of the real-world interactions versus the binary approach using a strictly rationalistic worldview. At the heart of the rationalistic worldview rests the assumption that reality is orderly and measurable and therefore, all things are understandable and explainable by logical analysis. However, various studies over the last twenty years have demonstrated that decision making in foreign policy rarely fulfills the model requirements of an orderly and measured rationality.[6] Instead, strategic related decisions increasingly take place in a volatile, uncertain, chaotic, and ambiguous environment.[7] Fuzzy logic provides methods of capturing this chaotic environment by simulating human behavior that is not simply restricted to absolute crisp

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[4] Steven D. Kaehler, "Fuzzy Logic - An Introduction."

[5] Nasser Ghasem-Aghaee and Tuncer I. Ören, "Towards Fuzzy Agents with Dynamic Personality for Human Behavior Simulation," *Proceedings of the 2003 Summer Computer Simulation Conference, (*Montreal, PQ, Canada, July 20-24, 2003): 3. According to Ghasem-Aghaee and Ören, non-fuzzy methods biggest weaknesses are their methods for dealing with the imprecision and uncertainty inherent in linguistics terms.

[6] Miriam Steiner, "The Search for Order in a Disorderly World: Worldviews and Prescriptive Decision Paradigms," *International Organization* 37, no. 3 (Summer 1983): 373-376.

[7] Yarger, *Little Book on Big Strategy*, 42.

binary values like 1 or 0.[8] This, in effect, enables a range or continuum of behaviors rather than all-or-nothing approaches, enabling strategic decisions based on perceptions of reality that are messy and imprecise.

Fuzzy logic characteristics expand the strategic decision space beyond the boundaries of a strictly binary decision-making mode. The advantage for the strategic decision maker is that fuzzy logic characteristics serve as "most useful tools of discovery" that "inject new sophistication into the interplay between theory and data."[9] Strategist Harry Yarger states, "Fuzzy logic helps to explain the ambiguity and uncertainty observed at this level—revealing more of the possibilities to the strategist, while at the same time qualifying expectations."[10] By expanding beyond simple all-or-nothing mindsets, fuzzy logic allows for degrees of deterrence or cooperation, as opposed to the goal of absolute deterrence required by Cold War models. Strategic decision makers instead seek some degree of deterrence rather than seeking absolute complete deterrence of a non-state actor or its individual components. Fuzzy logic expands the decision space for both the nation-state and non-state actors since cooperation is also no longer an all-or-nothing endeavor. By expanding the decision space, fuzzy logic in effect provides more options and choices for strategic decision makers that are not evident in a strictly binary approach.

Fuzzy logic handles the vague and imprecise perception of concepts like low, medium, high, hot or cold, short, tall, most or some. This ability to represent vagueness

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[8] Ghasem-Aghaee and Ören, "Towards Fuzzy Agents," 3.

[9] Charles C. Ragin, *Fuzzy-Set Social Science* (Chicago, Illinois: University of Chicago Press, 2000), 310.

[10] Yarger, *Little Book on Big Strategy*, 44.

and imprecision present in human language is an extremely useful characteristic for modeling non-state actor deterrence. In her article, “Can Deterrence be Tailored?” M. Elaine Bunn states that, “U.S. policymakers need mechanisms to assess how their words and actions are perceived, how they affect each adversary’s deterrence calculations, and how they might mitigate misperceptions that undermine deterrence.”[11] Fuzzy logic provides mechanisms to assess words and actions, which is important because words represent concepts that people generally have a cognitive sense or perception of, but are often impossible to define precisely.[12]

Finally, fuzzy logic characteristics enable the creation of fuzzy cognitive maps that are visual models providing levels of abstraction allowing for intuitive reasoning. Fuzzy cognitive maps are a vital capability because they enable strategic decision makers to understand how the components in a given situation interact. Additionally, fuzzy cognitive maps enable excellent simulation and prediction through fuzzy systems that are dynamic and can evolve using constant feedback loops. The models easily expand to handle increased factors related to deterring non-state actors such as credibility, nationalism, societal trends, and rationality.

Fuzzy logic encapsulates several characteristics useful for modeling non-state actor deterrence. The capability to represent the vagueness and imprecision of human language combined with the capacity to represent vagueness and ambiguity enable a more accurate model of the complex environment swirling around the strategic deterrence decision maker. This combination enables fuzzy logic to expand decision

[11] Bunn, “Can Deterrence be Tailored,” 1.

[12] Ghasem-Aghaee and Ören, “Towards Fuzzy,” 3.

space beyond all-or-nothing approaches. Consider strategist Harry Yarger's statement that fuzzy logic "has emerged to describe the greater complexity and corresponding openness in thinking required of the strategic environment. Fuzzy logic or 'fuzzy thinking,' however poorly named, helps illuminate the realities of the strategic environment because it provides allowances for degree, probability, and ambiguity in the formulation of objectives and concepts."[13] Allowance for probability, large degrees, and ambiguity are key terms in describing the non-state actor deterrence environment. Ellie Lieberman describes the phenomenon of deterrence as one characterized by temporal, dynamic, and causal dynamics.[14] Fuzzy logic tools describe, expand, and express this environment in ways strictly binary approaches cannot duplicate.

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[13] Yarger, *Little Book on Big Strategy*, 43.

[14] Lieberman, "Rational Deterrence Theory Debate," 385.

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CHAPTER 4

THE PRISONER'S DILEMMA

In fuzzy logic there is no absolute truth, just degrees of truth.
—Bart Kosko[1]

With the basics of deterrence and fuzzy logic characteristics in hand, a practical example is in order. This example uses a traditional game theory approach to deterrence, the classic Prisoner's Dilemma problem. In principle, game theory can represent any situation involving strategic interaction and decision making.[2] Essentially, game theory is the study of strategic communication of information through language in a rigorous and stylized way.[3] To be useful, a game theory model must be simple to understand while sharing important similarities with the complex real life situations they represent. Game theorists gain insight and new perspectives on complex problems by using models that are simplified versions of the issue.[4] Researchers utilize game theory and the Prisoner's Dilemma in particular across a variety of disciplines from law and economics to social science and politics to gain insights on social interactions and optimize strategies between competing players. Studying non-state actor deterrence with game theory via the Prisoner's Dilemma is useful. This chapter presents a strictly binary approach to the Prisoner's Dilemma, then compares and contrasts that binary approach to a fuzzy logic approach. The intent is to conceptualize how non-state actor deterrence

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[1] Kosko, *Fuzzy Thinking*.

[2] Tom Siegfried, *A Beautiful Math: John Nash, Game Theory, and the Modern Quest for a Code of Nature* (Washington DC: Joseph Henry Press, 2006), 2.

[3] Arfi, "Linguistic Fuzzy-Logic Game Theory," 29.

[4] Myerson, *Force and Restraint*, 5-6.

looks using fuzzy logic and to pinpoint useful characteristics and benefits of a fuzzy logic approach.

The Prisoner's Dilemma breaks down all actions to the root of choosing between cooperation and aggression.[5] The game operates from the point of view that all players behave rationally and pursue what is in their best interest.[6] Kalyan Raman, a fuzzy logic practitioner, applied fuzzy logic to the Prisoner's Dilemma (PD) and found:

> In the classical version of the PD, it is indeed the case that the prisoners can only cooperate or defect. But decision makers do not always face a stark choice between total cooperation and total non-cooperation….This analysis shows that fuzzy control enjoys a number of advantages over classical crisp analysis in resolving the PD. Action spaces are often continuous in the real world, human rationally is bounded and people rely on heuristics to simplify cognitive complexity and ease decision-making….Fuzzy control shows that the inherent bounded rationality and heuristic nature of human decision-making lead in a natural way to an abundance of partially cooperative outcomes.[7]

Raman demonstrates fuzzy logic's advantages over the binary approach to game theory reliance on limiting choices to simply "yes" or "no," 1 or 0. His analysis shows strategic decision-making action space is generally more robust than simple choices between complete cooperation and complete aggression. Raman 's approach to the Prisoner's

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[5] The Prisoner's Dilemma is a fundamental problem in game theory that demonstrates why two people might not cooperate even if it is in both their best interests to do so. The Prisoner's Dilemma originally presented the options to cooperate or defect. This monograph chooses to use cooperation or aggression to represent non-state actor deterrence.

[6] Tom Siegfried, *A Beautiful Math*, 21. This book provides an excellent background on game theories origins and John Nash's contribution to game theory. John Nash astounded the mathematics world in the 1950s with his work in game theory. In 1994, Nash shared the Nobel Prize with John Harsanyi and Reinhard Selten for their work in the field of game theory that analyzes how choices are made in contests of strategy.

[7] Kalyan Raman, *A Fuzzy Resolution of the Prisoner's Dilemma* (School of Management, University of Michigan, Flint, 2002), 11.

Dilemma offers decision makers an infinite variety of rational choices between cooperation and aggression.[8]

The classic Prisoner's Dilemma game involves two players, A and B, who must choose between cooperation and aggression. Players receive either a positive payoff or negative consequences based on their choices (Table 1). For example, let player A represent the U.S. and player B represent a non-state actor. If the non-state actor is cooperative then the U.S. expects a payoff of either 1 (cooperation) or 3 (aggression) depending on whether the U.S. chooses cooperation or aggression. The best course of action for the U.S. is aggression, which results in the maximum positive payoff of 3. Conversely, if the non-state actor is aggressive, then the U.S. expects negative consequences of either -10 (cooperation) or -3 (aggression). Again, the best course of action for the U.S. is aggression resulting in a negative consequence of -3.[9]

Table 1. Basic Prisoner's Dilemma game

		B: (Non-state Actor) Cooperative	Aggressive
A: (United States)	Cooperative	A: 1, B: 2	A: -10, B: 3
	Aggressive	A: 3, B: -8	**A: -3, B: -5**

Bold type represents Nash equilibrium as defined by John Nash[10]

[8] Although Raman's approach to a fuzzy Prisoner's Dilemma differs from the one this monograph presents, his findings and conclusions buttress the concepts presented throughout this monograph.

[9] Myerson, *Force and Restrain*, 6-7. The model this monograph utilizes is based on Myerson's Prisoner's Dilemma model.

[10] Tom Siegfried, *A Beautiful Math*, 2 and 56-59. If each player has chosen a strategy and no player can benefit by changing his strategy while the other players keep their unchanged, then the current set of strategy choices and the corresponding payoffs constitute a Nash equilibrium. John Nash demonstrated a mathematical method to find this equilibrium. See Appendix I for a detailed example of calculating a Nash equilibrium.

Similarly, from the non-state actor point of view, if the U.S. is cooperative, then the non-state actor expects a payoff of either 2 (cooperation) or 3 (aggression). The best course of action for the non-state actor is aggression, resulting in a payoff of 3. On the other hand, if the U.S. is aggressive, then the non-state actor expects a payoff of either -8 (cooperation) or -5 (aggression). The best course of action for the non-state actor is aggression resulting in a -5 payoff.

Table 1 shows that neither side can reach their goals by provoking the other player. A non-state actor threatening the U.S. through aggression results in a high level of U.S. response that is unsatisfactory to the non-state actor. Likewise, an overly aggressive U.S. approach leads to unsatisfactory levels of aggression from the non-state actor. The obvious "Win, Win" is for players to cooperate with each other and reap positive rewards of 1 (United States) and 2 (non-state actor). However, because the payoff is always higher for aggression than cooperation, aggressive action benefits whoever acts in their self-interest. This leads to a "Lose, Lose" situation because aggressive action yields negative consequences for both players.

Figure 3 represents the decision space available to the U.S. when limited to all-or-nothing choices in the binary Prisoner's Dilemma game. The graph illustrates the U.S. either receives a payoff of 1 for cooperation of a payoff of 3 for aggression against a cooperative non-state actor. The graph further illustrates the negative consequences the U.S. receives of -10 for cooperation or -3 for aggression against an aggressive non-state actor. The only choice the U.S. can make is between either complete cooperation or complete aggression. The unutilized decision space between these two extremes demonstrates the binary approaches' lack of nuance and flexibility. Additionally, the

used decision space illustrates how the binary approach severely limits options available to the decision maker.

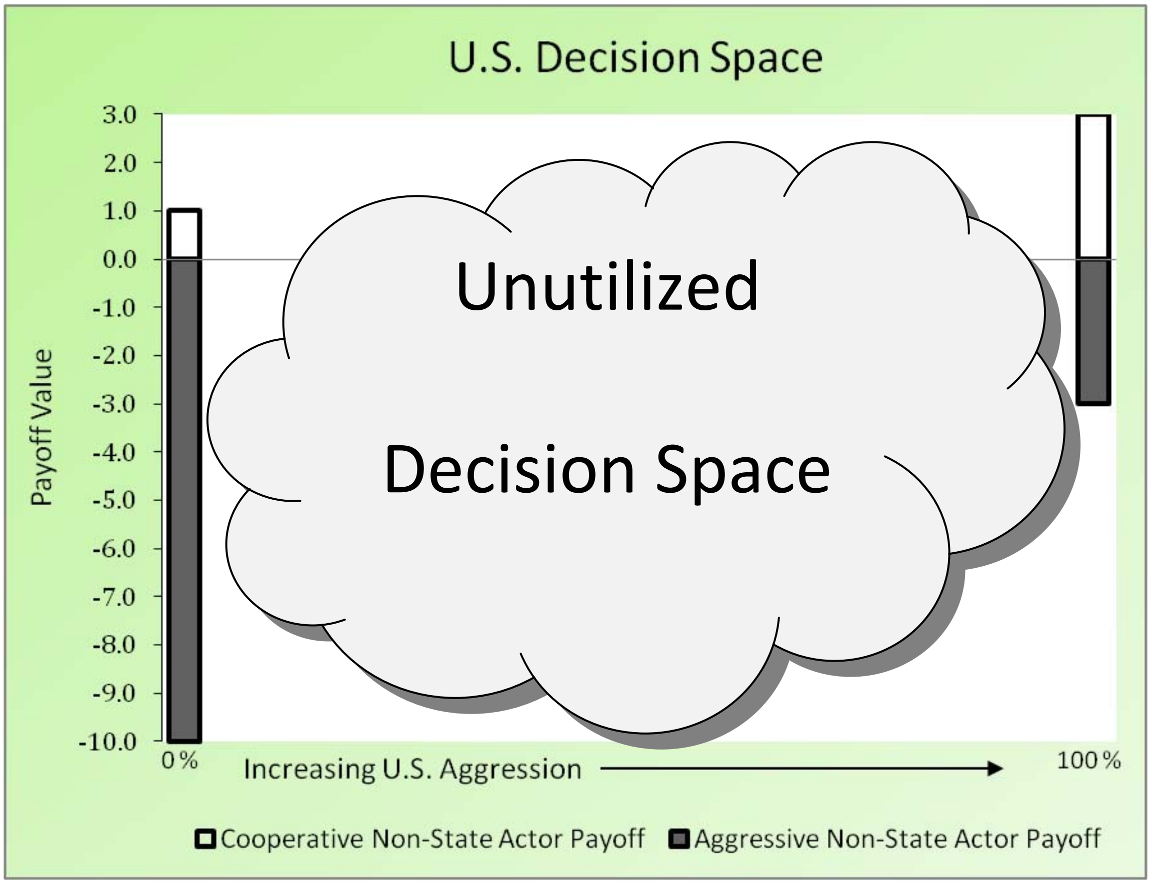

Figure 3. U.S. decision space for the Prisoner's Dilemma using a binary approach.

Charles Ragin presents fuzzy logic as a "most useful as tools of discovery. They inject new sophistication into the interplay between theory and data. Because of the close correspondence between fuzzy sets and concepts, fuzzy sets transform and enrich this interplay."[11] Transforming the Prisoner's Dilemma from a strict binary framework into a fuzzy logic framework requires three basic steps. These three steps are common to building any fuzzy system: pick the nouns or variables; pick the fuzzy sets that define the

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[11] Ragin, *Fuzzy-Set Social Science*, 310.

nouns; and set-up rules for the system.[12] Using the Prisoner's Dilemma example, the variables or nouns are cooperation and aggression. The fuzzy sets that define cooperation and aggression are simple s-curves created using a normal distribution function. Figure 4 illustrates the new player strategic decision space created by simply expanding the options from strictly all-or-nothing to degrees of cooperation and aggression. The two fuzzy sets in Figure 4 clearly illustrate the concept that an actor's cooperation or aggressiveness can vary by degrees.

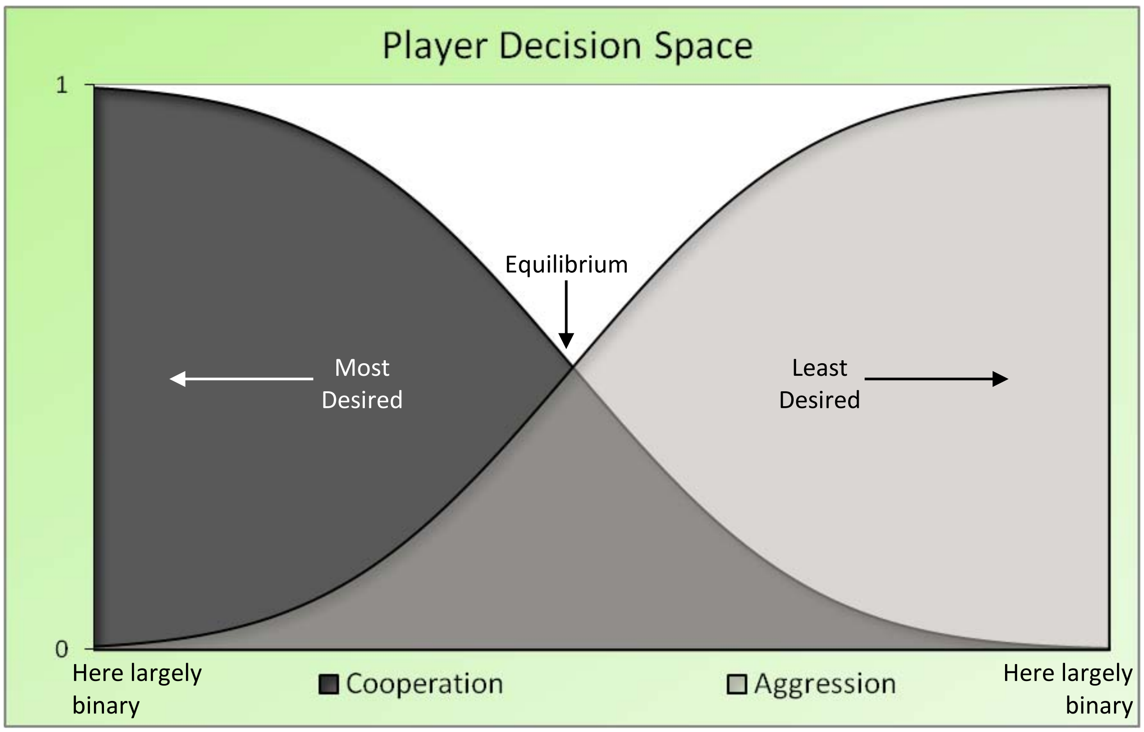

Figure 4. Decision space of a fuzzy logic Prisoner's Dilemma.

With the basic framework defining the fuzzy decision space in hand, it is appropriate to return to the Prisoner's Dilemma and analyze player choices. While players still earn payoffs based on their choices, their decision space is no longer limited

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[12] Kosko, *Fuzzy Thinking*, 161.

to a binary choice between either 0 or 100 percent cooperation and aggression. Players now choose between degrees of either cooperation or aggression. According to Table 1 for example, if the non-state actor is cooperative to some degree then the United States expects some degree of payoff between 1 (cooperation) and 3 (aggression). The payoff to the non-state actor for cooperation is some degree ranging between 2 and -8. Conversely, if the non-state actor is aggressive to some degree, then the United States expects a payoff between -10 and -3, while the payoff to the non-state actor in this case ranges from 3 to -5.

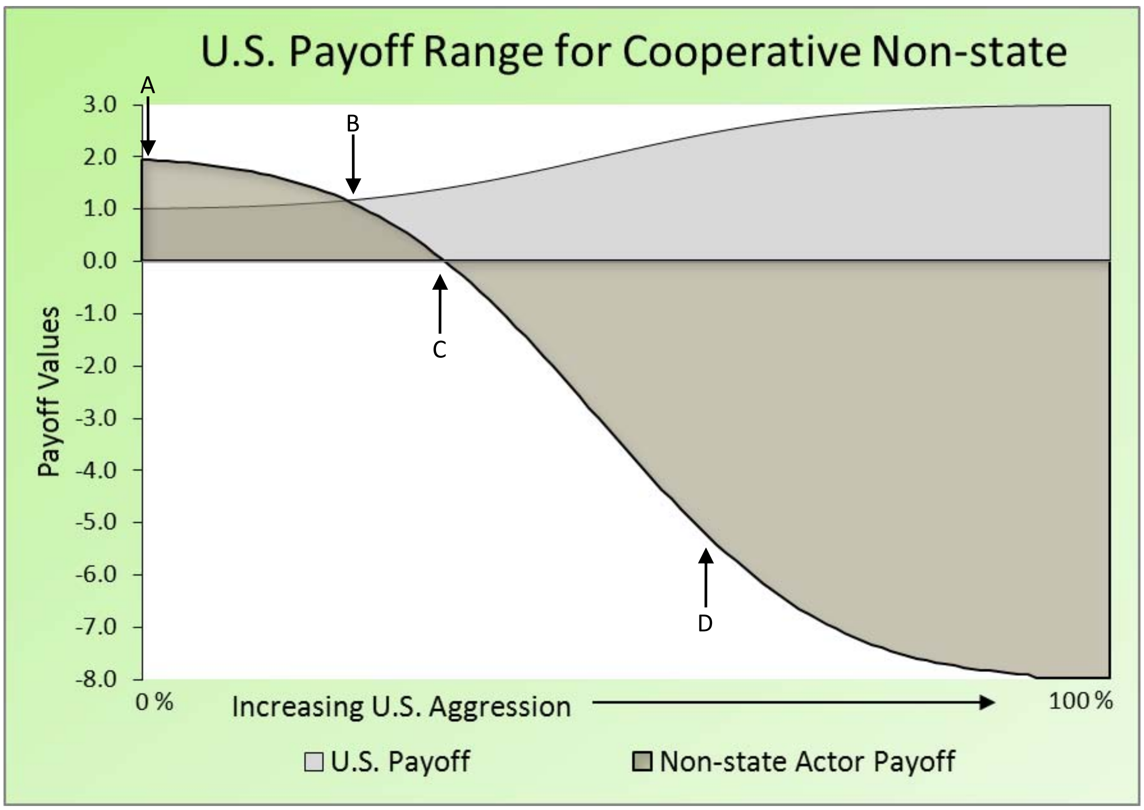

Figure 5. United States payoff range with a cooperative non-state actor.

Figure 5 illustrates United States payoff range for cooperative non-state actor. The figure relates increasing aggression to increased payoff for the United States with an associated increasingly negative payoff for the non-state actor. The entire graph

represents a potentially partial cooperative decision space and clearly illustrates that the decision space expands when using degrees of aggression. The result is a wide number of potential payoffs of varying amounts.

At the extremes of 0 or 100 percent, the model defaults to the traditional binary result where aggression still provides the highest payoff for the United States. However, a closer look at the points between the extremes (letters A – D) reveals important insights the fuzzy decision space represents. While any point between A and C is a "win, win" for both actors, point A represents a logical extreme where non-state actor return is maximized. In the area between points A and C, the U.S. payoff increases as aggression increases and non-state actors receive a positive payoff. For strategic decision makers, this area represents the potential for non-state actors to save face by receiving some gain, while at the same time there is a sufficient level of payoff for the U.S.

As aggression increases between points A and B, non-state actor payoff is still relatively high for cooperation while the U.S. aggression component is relatively negligible. Point B is the best "win-win" for both actors by maximizing return without resorting to all-or-nothing approaches. Aggression continues to increase along the curve to point C, which indicates the maximum U.S. payoff, while the non-state actor garners zero return. Beyond point C, U.S. returns increase and non-state actor returns trend into negative territory, representing increased pressure on the non-state actor. Finally, point D while not 100 percent aggression represents a choice for the strategic decision maker to punish the non-state actor. Point D inflicts a degree of pain on the non-state actor, but still leaves room to turn up the heat by increasing aggression in the future. Conversely, if

the non-state actor responds positively, the U.S. may decrease aggression resulting in increased payoff benefits for the non-state actor.

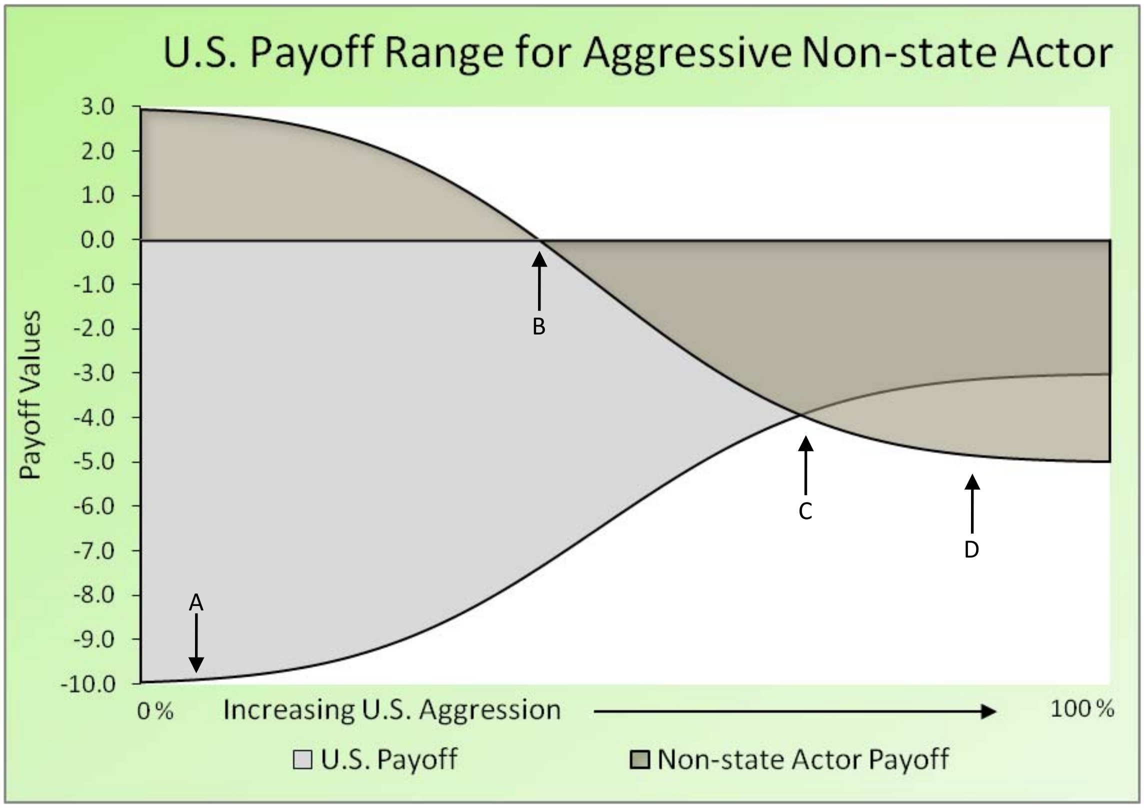

Figure 6. United States payoff range with an aggressive non-state actor.

Figure 6 illustrates U.S. payoff range as aggression increases when the non-state actor is aggressive. Similar to Figure 5, the entire graph represents potential degrees of aggression in the decision space. At the extremes, the fuzzy approach continues to reflect the traditional binary Prisoner's Dilemma conditions. The value for the strategic decision maker lies in the area along the payoff curves between the extremes. Point B indicates where the non-state actor's payoff transitions from positive to negative potential. Point C represents the worst-case scenario "win-win" because the negative consequences for both actors are equivalent. The area between points B and C provides the U.S. the highest rate

of return for aggression. Beyond point C, the non-state actor's payoff trends toward maximum negative, while U.S. payoff rate increases at a decreasing rate.

This simplified Prisoner's Dilemma model demonstrates fuzzy logic's characteristics and utility as a tool for non-state actor deterrence. Careful analyses of the results of the binary Prisoner's Dilemma contrasted with the results of the fuzzy Prisoner's Dilemma illustrate the limits of applying binary methods to non-state actors. Unlike the binary method, the fuzzy logic approach supports the concept of a decision that is both partially cooperative and partially aggressive. Nor does the fuzzy logic approach force decision makers to choose between strictly binary or strictly fuzzy methodologies because fuzzy logic sets encompass full membership, full non-membership, and an infinite set of choices in between. Using fuzzy sets, therefore, enable multiple interpretations and more decision space for decision makers.[13]

Fuzzy logic allows for the human characteristic of uncertainty. Uncertainty of the starting conditions, of the environment, uncertainty as to the possible payoffs or benefits, and by extension, uncertainty as to the possible losses or costs of cooperation or aggression. The binary Prisoner's Dilemma decision space forces actors to choose between two extremes and, in doing so, removes uncertainty. However, by allowing for degrees of cooperation or aggression, fuzzy logic captures the inherent uncertainty of human beings who do not always act in rational ways, or in their own best interests.

Literal interpretation of the Prisoner's Dilemma constrains the choices to strictly 100 percent threat or 0 percent threat (no threat) which presents several difficulties for

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[13] Ragin, *Fuzzy-Set Social Science*, 8-9.

strategic decision makers. This constraint on decision makers is artificial and not very realistic or representative of the real world policy interactions. For example, in the case of sanctions against a rogue nation the level of a punitive consequent could scale up or down over time. The degree to which the rogue nation perceives the sanctions as a threat (aggression) increases as the level of sanctions increase. Conversely, as the level of sanctions decreases this implies some degree of cooperation by the rogue nation as well as the other party. The concept of degrees stands in stark contrast to all-or-nothing approaches to threats, which is confining, makes cooperation difficult to achieve, and leaves actors little room for maneuvering or adjustment. The fuzzy perspective enables the emergence of partially cooperative results or degrees of cooperation in response to some degree of cooperation or aggression from the other actor.[14] This crucial aspect of the fuzzy model allows for the flexibility and dynamics present in real-world interactions where actors are rarely 100 percent cooperative, 0 percent cooperative, 100 percent aggressive, or 0 percent aggressive. In effect, the decision-making space for the actors becomes an entire continuum of options and choices, rather than simplistic choices between either all cooperation or all aggression.

Most importantly, the model easily expands to handle an increased rule set that might include factors related to deterring non-state actors such as credibility, nationalism, societal trends, and rationality. Each of these factors could be further modified with the use of hedge words like *somewhat*, *more likely* or *less likely*, and *almost always*. For example, an actor could be *somewhat aggressive* or *almost always cooperative*. In

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[14] Raman, *Fuzzy Resolution Prisoner's Dilemma*, 2.

"Linguistic Fuzzy Logic Game Theory," Badredine Arfi explored "nuanced cooperation" concept, which he identifies as "*high cooperation* with a *very high feasibility* or nuanced cooperation such as *very high cooperation* with a *very low feasibility,* not just of cooperation or non-cooperation."[15] Figure 7 illustrates the results of combining hedge words with the fuzzy Prisoner's Dilemma decision space.

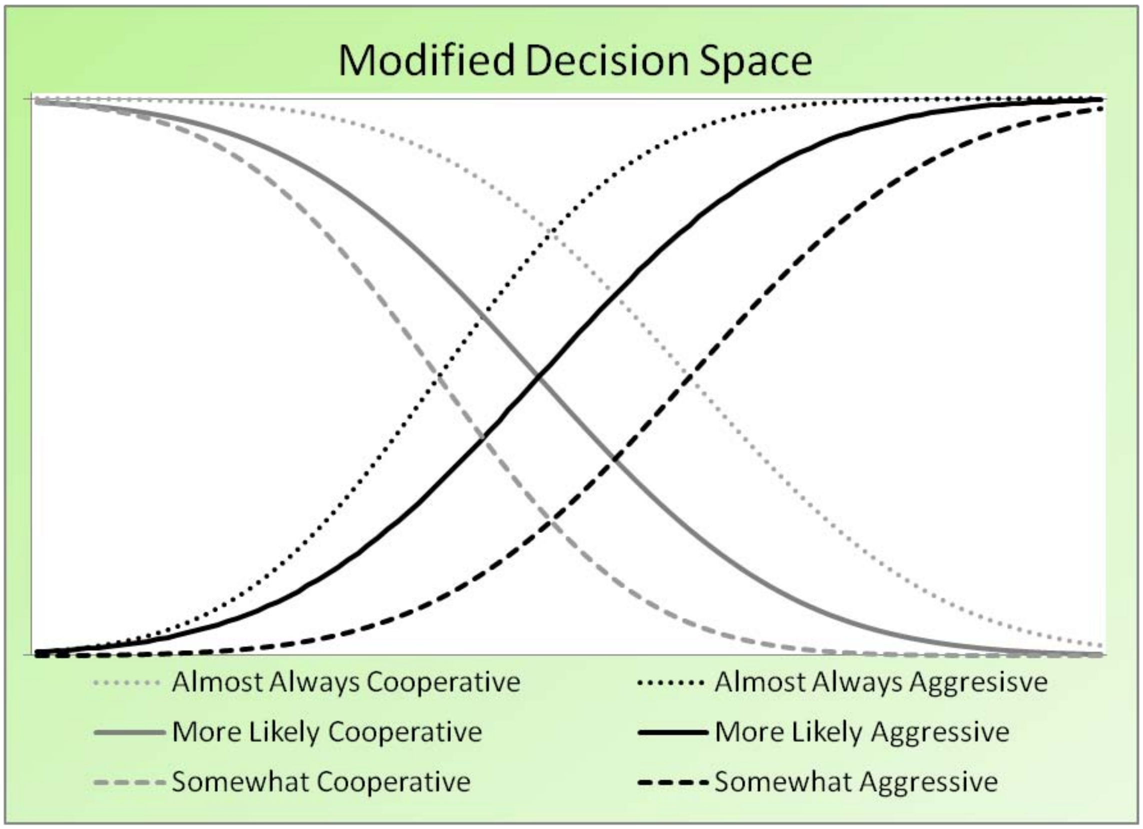

Figure 7. Modified decision space reflecting concepts of somewhat, more likely and almost always.

Combining hedge words with new factors yields a more nuanced rule set and enable more realistic and customizable models. For example, how does the decision space look with a *somewhat cooperative* player versus an *almost always aggressive*

[15] Arfi, "Linguistic Fuzzy-Logic Game Theory," 29.

player? The shifting graph illustrates decision space changes representing the idiosyncrasies of different players. Using hedge words enables decision makers to adapt and fine-tune the fuzzy action space to particular actors.

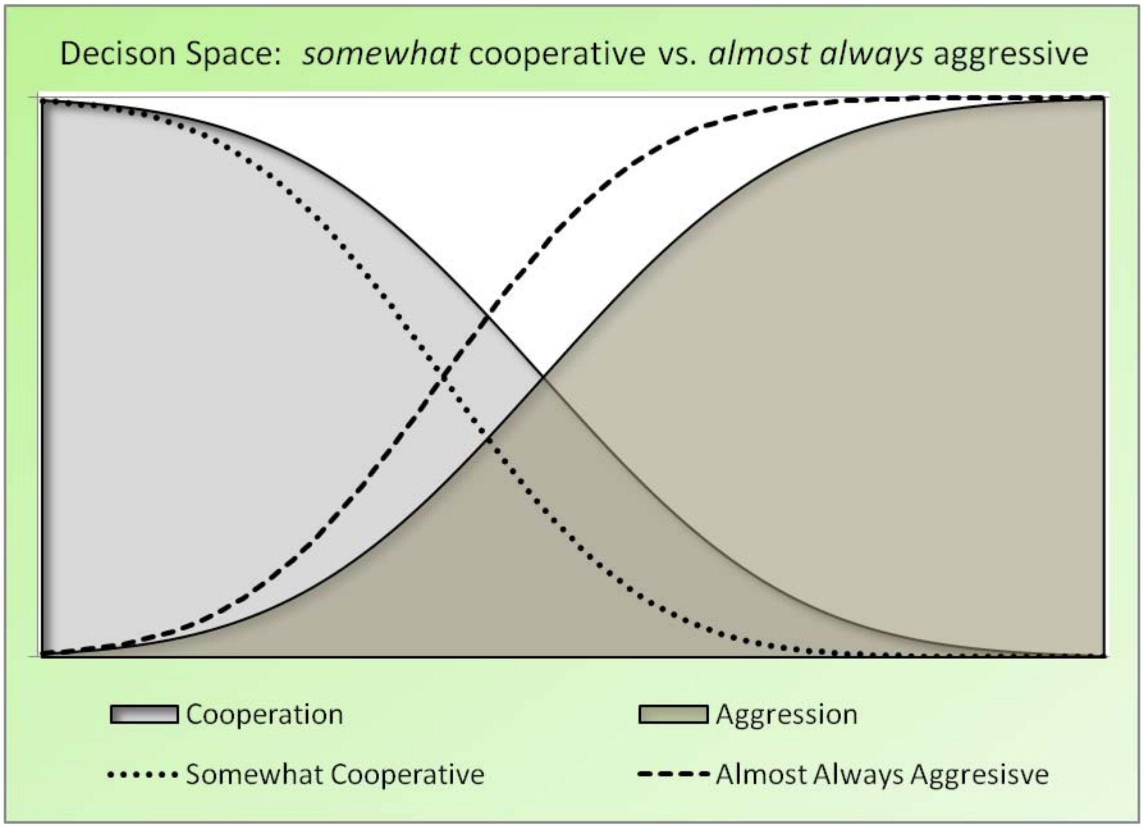

Figure 8. Modified decision space reflecting somewhat cooperative versus almost always aggressive.

Figures 7 and 8, demonstrate how the fuzzy logic approach allows for an infinite number of aggression inputs and a corresponding infinite number of cooperation responses, implying that each actor has much more maneuvering room than to be simply 100 percent aggressive or 100 percent cooperative. Because, when actors classify the threats as black or white, they always generate a binary pattern of cooperation and aggression. Kalyan Raman voices the following insight, “In problems where a continuous action space makes conceptual sense, the fuzzy control formulation shows a

great deal of promise for generating partially cooperative outcomes."[16] By considering threats as a matter of degrees, instead of 1 or 0, fuzzy logic generates a continuum of cooperation patterns ranging from complete cooperation to complete non-cooperation with an infinite number of degrees between them.[17] Two actors can go to war 100 percent or not go to war 100 percent in a Boolean sense, but it is more accurate and realistic to conclude that actors can, more or less, go war by degrees. The actors are in a no-peace situation, but not in a fully-fledged state of war.[18] One could easily argue that Vietnam, Korea, Gulf War I, Gulf War II, and the current Afghanistan situation do not characterize war in an all-or-nothing sense, but rather represent wars of degree.

Fuzzy logic is more flexible and representative of real world human interactions, whether nation-state versus nation-state or nation-state versus non-state actor. As Kalyan Raman expressed it:

> In the binary treatment of the [prisoners' dilemma], the outcome is considered to be completely non-cooperative below a threshold level, and above this threshold, the outcome is considered to be completely cooperative. In the fuzzy treatment of the [prisoners' dilemma], the outcome is considered to be increasingly non-cooperative as we go lower and lower below a threshold level, and the outcome is considered to be increasingly cooperative as we go higher and higher above this threshold. Thus, in the fuzzy framework, cooperation is a matter of degree rather than an 'All or Nothing' outcome.[19]

Applying fuzzy logic to the Prisoner's Dilemma demonstrated complexities and possibilities that were not evident when utilizing a crisp Boolean logic approach. Furthermore, the fuzzy logic Prisoner's Dilemma provided a richer view of strategic

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[16] Raman, *Fuzzy Resolution Prisoner's Dilemma*, 11.

[17] Ibid., 4.

[18] Arfi, "Linguistic Fuzzy-Logic Game Theory," 33.

[19] Raman, *Fuzzy Resolution Prisoner's Dilemma*, 4.

decision space as opposed to the binary Prisoner's Dilemma. The world presented in color (or at least gray-scale) rather than less realistic, two-dimensional black and white choices.

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CHAPTER 5

FUZZY COGNITIVE MAPS

FCMs [Fuzzy Cognitive Maps] help us see the big picture and do something with it…
—Bart Kosko[1]

The previous chapter explored fuzzy logic's ability to expand the strategic decision maker's decision space by applying fuzzy logic to non-state actor deterrence using the Prisoner's Dilemma game. This chapter extends the toolset for non-state actor deterrence by introducing fuzzy cognitive maps (FCMs). FCMs draw causal pictures or diagrams of complex systems by tying facts, things, and processes together with policies, values, and objectives. Numerous fields utilize fuzzy cognitive maps extensively for modeling, planning, and decision-making processes events in politics, history, medicine, and military planning to analyze, predict, and understand how complex events might interact and play out.[2] According to their creator, Bart Kosko, "A FCM stands behind every op-ed article and every political speech."[3] Because op-ed articles and political speeches are all about drawing causal pictures and tying things together with policies, using FCMs to depict them is intuitive. Kosko further asserts, "FCMs are especially applicable in soft knowledge domains (e.g. political science, military science, history, international relations, [and] organizational theory) where both the system concepts/

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[1] Kosko, *Fuzzy Thinking*, 224.

[2] Gerald D. Calais, "Fuzzy Cognitive Maps Theory: Implications for Interdisciplinary Reading: National Implications," *FOCUS On Colleges, Universities, and Schools* 2, no. 1 (2008): 15.

[3] Kosko, *Fuzzy Thinking*, 222.

relationships and the meta-system language are fundamentally fuzzy."[4,5] Non-state actor deterrence easily fits into the soft knowledge domains Kosko mentions and therefore is an ideal candidate for fuzzy cognitive maps. This chapter presents three examples demonstrating the utility of applying fuzzy cognitive maps to non-state actor deterrence.

Like game theory and the Prisoner's Dilemma, cognitive maps are not a new. Simply put, cognitive maps are mental models that enable individuals to visualize information. In cognitive maps, nodes represent concepts, or factors, and lines connecting the nodes represent connections between concepts. Cognitive maps can represent both simple and very complex ideas. In 1976, political scientist Robert Axelrod first applied cognitive map techniques, in his book *Structure of Decision: The Cognitive Map of Political Elites*, to model political and social system decision-making processes. Axelrod proposed a system based on what he called the notion of causation as "vital to the process of evaluating alternatives. Regardless of philosophical difficulties involved in the meaning of causation, people do evaluate complex policy alternatives in terms of the consequences of a particular choice would cause, and ultimately of what the sum of all these effects would be."[6] Axelrod's cognitive maps are a specific way for graphically representing a person or group's approach to some problem in a manner that aids causal

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[4] Bart Kosko, "Fuzzy Cognitive Maps," *International Journal of Man-Machine Studies* 24, no. 1 (January 1986): 65. With respect to military science as a "soft" knowledge domain, Kosko is not referring to the science of war, but the art.

[5] Costas Neocleous, Christos Schizas, and Costas Yenethlis, *Fuzzy Cognitive Models in Studying Political Dynamics: The Case of the Cyprus Problem* (Nicosia: University of Cyprus). For example, see the fuzzy cognitive map of the Cyprus problem using nodes: nationalism, religiousness, knowledge of history, level of educational development, tourism, oil, other natural resources, Anatolian settlers, and the general interests of the countries involved, as well as the interests of the two predominant communities. The authors present different scenarios that are analyzed and used as instructional and research tools.

[6] Axelrod, Robert, ed., *Structure of Decision: The Cognitive Maps of Political Elites,* (Princeton, NJ: Princeton University Press, 1976), 5.

and structural analysis. The consequences that follow from this structural representation are used to derive explanations of the past, make predictions of the future, and choose polices for the present.[7] Figure 9 depicts part of a cognitive map drawn from Axelrod's empirical study of the British Eastern Committee who were responsible for British policy from the Mediterranean Sea to India.

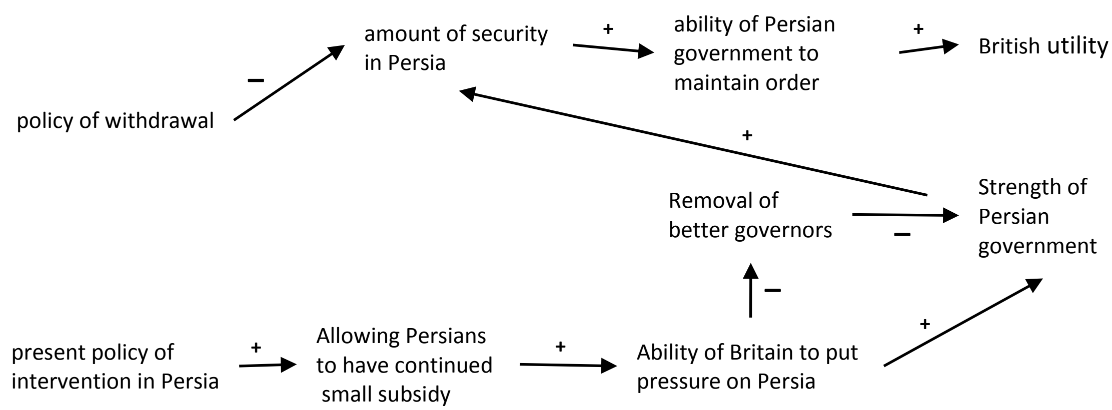

Figure 9. Axelrod's cognitive map of British Eastern Committee policy analysis.[8]

In 1986, fuzzy logic pioneer Bart Kosko applied fuzzy logic concepts to cognitive maps resulting in a structure that represents causal reasoning. Kosko added fuzzy logic to overcome shortcomings in cognitive maps' hierarchal structure. These shortcomings prohibit feedback and prevent cognitive maps from reflecting the dynamic interplay present in the real world interactions.

To fuzzify cognitive maps, Kosko fundamentally changed cognitive maps in four ways. First, he weighted the connection arrows that link nodes by assigning them values between -1 and 1 or more descriptively by words like "somewhat," "more," "a bit," or "a

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[7] Robert, *Structure of Decision*, 55.

[8] Ibid., 61.

lot." In doing so, he enabled the cognitive map to represent degrees of influence between nodes. Second, he made the concept nodes themselves fuzzy by allowing their values to range between 0 and 1. Now, instead of a concept node being restricted to just on or off, the node could be on to some degree. Furthermore, his concept node's response to stimuli would not be binary. Instead, the node could react in any number of ways in response to stimuli. Third, Kosko made the rules governing the cognitive map all fire at the same time with varying degrees of affect (zero or 100 percent or any range in between). By doing so, Kosko enabled all rules, nodes, and connections to participate in the cognitive map to some degree. Fourth, Kosko changed cognitive maps from a strictly hierarchal structure to one of dynamic interplay by adding feedback loops. Adding feedback meant one node might affect another node, which in turn could affect the original node. The overall effect is that nodal influences propagate throughout the system in unpredictable ways making cognitive maps more dynamic and real world like because changes in the cognitive map reverberate throughout the system.[9]

Kosko called these structures fuzzy cognitive maps (FCMs) and asserts they "lay bare your beliefs and biases and your grasp of the world. They help the most in the value clashes that mix the head and the heart."[10] By making the nodes and the causal connections between them fuzzy instead of binary, fuzzy cognitive maps blend fuzzy logic's ability to represent uncertainty, ambiguity, and vagueness with cognitive maps' ability to represent complex systems graphically and show cause and effect among

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[9] Kosko, *Fuzzy Thinking*, 222-225.

[10] Ibid., 229-230.

concepts.[11] Fuzzy cognitive maps are extremely flexible because concept nodes can represent and relate to anything ranging from events, actions, goals, and values to other fuzzy cognitive maps.[12] This ability gives FCMs the flexibility to model events, actions, goals, values, or even to connect together other FCMs to model extremely complex and chaotic systems.

There are two types of FCM nodes: policy nodes and value nodes. Value nodes have causal arrows flowing into or out of them. Policy nodes on the other hand, have no causal arrows flowing into them because according to Kosko, "you or God or government control it."[13] By controlling and adjusting policy node inputs, decision makers ask "what-if" questions and observing how the FCM reacts. Vague or imprecise inputs propagate and cascade through the fuzzy feedback system as interconnected nodes turn on or off to various degrees. Kosko asserts FCMs quickly converge or reach equilibrium in one of three states.[14] This convergence is an important feature of FCMs because it enables one to see what happens when holding policy nodes to certain values. Once the FCM converges, the output equilibrium is effectively the answer to the causal "what-if" question the user asked by adjusting the policy inputs to the FCM.[15]

One way to understand the concept of fuzzy cognitive maps is to imagine the FCM as the surface of a pond. Throwing a rock into the pond causes a cascade of ripples

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[11] Jose Aguilar, "A Survey about Fuzzy Cognitive Maps Papers," *International Journal of Computational Cognition* 3, no. 2 (June 2005): 27.

[12] Julie A. Dickerson and Bart Kosko, "Virtual Worlds as Fuzzy Cognitive Maps," *Presence* 3, no. 2 (Spring 1994): 174-175.

[13] Kosko, *Fuzzy Thinking*, 224.

[14] Kosko, "Fuzzy Cognitive Maps," 65-75.

[15] Dickerson and Kosko, "Virtual Worlds," 174-175.

that move and interact across the pond's surface, eventually settling down into a new state. Bart Kosko calls FCMs cascading feedback loops the fuzzy causal "juice" that swirls around the FCM. The fuzzy causal "juice" swirls around and flows through the fuzzy feedback system as nodes fire seeking equilibrium. This interaction continues until reaching equilibrium where cascading effect propagating through the system settles into one of three states after some number of iterations.

The first possible state is a fixed node value called the fixed-point attractor. For instance, take a FCM with nodes A-D. A change to the FCM causes a cascade of feedback loops along interconnected nodes until eventually the reverberations reach equilibrium by settling on C. Node C becomes the fixed-point attractor, effectively answering the "what-if" question the decision maker asked.

Alternatively, the FCM may cycle between several fixed states, known as a limit cycle. As effects propagate and swirl throughout the fuzzy cognitive map, the FCM does not reach equilibrium at a single node, but cycles between nodes in the FCM in a recognizable repetitive pattern of nodes A, D, C, A, D, C, etc. In this case, the answer to the decision maker's "what-if" question is a combination of nodes.

The third possibility is what Kosko calls a chaotic attractor. In this case, some chaotic input is continually injected into the system. Then, instead of stabilizing, the fuzzy cognitive map continues to swirl around and never settles down. No single node or pattern emerges indicating the FCM has reached equilibrium. Instead, the FCM reaches a variety of output values in a purely random way.

Using fuzzy cognitive maps for decision support provides several advantages for strategic decision makers. According to Rod Taber, a fuzzy logic expert, "perhaps the

greatest case for the FCM approach is ease of use."[16] FCMs are simple, flexible, and powerful tools enabling decision makers to analyze and model the world as a collection of concepts and causal relationships.[17] As a visual model, FCMs provide a concise way of expressing concepts at a level of abstraction that allows for intuitive reasoning. By transforming a decision-making process into a fuzzy cognitive map, decision makers without the in-depth background of a problem can rapidly gain an understanding of the underlying components in a given situation.[18] FCMs enable realistic simulation and prediction, while handling incomplete, vague, unreliable, and conflicting information. FCMs thrive on constant feedback loops making the system dynamic instead of static.[19] For example, a change in one fuzzy node affects one or more other nodes to some degree between -1 and 1, which in turn affects one or more additional nodes. This nodal interaction creates a chain reaction cascading through the entire FCM as nodes influence their neighbors to various degrees. This feedback is critical because the real world is not static. Actors react and adjust as they interact with their environment and each other. With fuzzy techniques, it is possible to identify and consider the most relevant

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[16] Rod Taber, "Knowledge Processing with Fuzzy Cognitive Maps," *Expert Systems with Applications* 2, no. 1 (1991): 83. Taber lists five stages for FCM development: source selection, map acquisition, conversion to matrix from, inference, and global knowledge base construction. One approach to FCM development is for experts in the subject of study diagram the problem using FCMs. Taber asserts, a better approach is for multiple experts to draw individual FCMs and then combine them. These combined FCMs are potentially stronger because information contained in the FCMs is derived from multiple sources making single data point errors less likely.

[17] Ilker Akgun, Ahmet Kandakoglu and Ahmet Fahri Ozok, "Fuzzy integrated vulnerability assessment model for critical facilities in combating the terrorism," *Expert Systems with Applications* 37, no. 5 (2010): 3565. Paper presents realistic approach using fuzzy cognitive maps to determining the vulnerability of critical facilities, such as airports, dams, nuclear power plants.

[18] Jose Salmeron, "Supporting Decision Makers with Fuzzy Cognitive Maps," *Research-Technology Management* 52, no. 3 (2009): 53-59.

[19] Kosko, *Fuzzy Thinking*, 224.

environmental factor that appears to affect the targeted nodes.[20] Fuzzy cognitive maps provide the capability to help identify the elements or individuals that support or influence non-state actors that are deterrable.

Uygar and Stacy L. Özesmi, in their analysis of fuzzy cognitive maps, emphasize FCMs as a decision-making support tool that improves information flow between participants. In addition, the Özesmis identify several problem sets ideally suited for FCMs and especially applicable to the non-state actor deterrence problem. First, problem sets involving FCMs depicting situations where human behavior plays a significant role and fuzzy logic's ability to represent imprecise and vague quantities is a key capability. Second, problem sets where factual scientific data is uncertain, incomplete, or unavailable. Third, complex issues with no simple or correct answers that incorporate numerous and varied positions where seeking and finding compromise is often the only solution to the issue.[21]

Fuzzy cognitive maps can nest inside each other enabling any number of fuzzy sets to serve as inputs in an overall fuzzy cognitive map. Because, FCMs are pictorial, they are generally quick and easy to acquire from multiple knowledge sources. Furthermore, combining FCMs from a variety of knowledge sources with varying degrees of expertise and experience is relatively straightforward.[22] Linked FCMs apply to a variety of situations where complex behavior can be modeled and analyzed by

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[20] Salmeron, "Supporting Decision Makers," 53-59.

[21] Uygar Özesmi and Stacy L. Özesmi, "Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach," *Ecological Modelling* 176, no. 1-2 (August 2004): 43-64. The fourth case is a fuzzy cognitive map incorporating public opinion.

[22] Özesmi and Özesmi, "Ecological models," 43-44.

changing the magnitude or sign of a single fuzzy cognitive map rule or modifying nodal interaction.[23] A problem area is divided into smaller fuzzy sets or sub-problems and each map is linked along its edges, enabling the fuzzy subsets to influence the overall fuzzy cognitive map. For example, a non-state actor may view an overall survival threat as comprised of three fuzzy subsets: small threat, medium threat, and large threat. Dividing the problem into subsets also enables modularity and rearrangement of fuzzy cognitive map.

Three examples illustrate fuzzy cognitive maps' potential for understanding a non-state actor's decision-making calculus and demonstrate the flexibility, adaptability, and utility of fuzzy cognitive maps. The first example is Kosko's Mideast FCM (Figure 12) and involves the Palestinian Liberation Organization (PLO). In June 18, 1982, Henry Kissinger wrote "Starting Out in the Direction of Middle East Peace" for the *Los Angeles Times*. Kissinger's article addressed the complexities of Middle East peace with particular regard to Lebanon and PLO-Israeli negotiations.[24] Kosko created a fuzzy cognitive map from Kissinger's article to test the FCM concept. In this particular FCM, *Islamic Fundamentalism* is the only policy node. Arrows between the nodes represent the existence of a fuzzy rule defining a causal link, or connection, between objects. These connections affect the nodes to some degree. The plus (+) sign next to an arrow indicates a causal increase, while a minus (-) sign indicates a causal decrease.[25]

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[23] Dickerson and Kosko, "Virtual Worlds," 178-187.

[24] Henry A. Kissinger, "Starting Out in the Direction of Middle East Peace," *Los Angeles Times*, June 18, 1982.

[25] Kosko, "Fuzzy Cognitive Maps," 66.

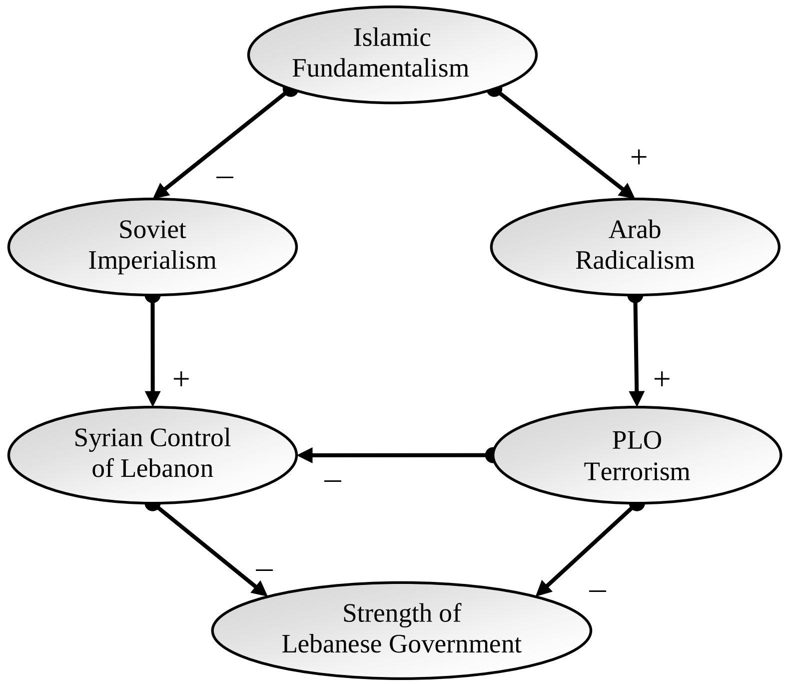

Figure 10. Kosko's fuzzy cognitive map of Islamic Fundamentalism.[26]

This FCM is an excellent example showing the relationships between nodes and potential interactions based on Kissinger's depiction of conditions influencing Middle East peace. In Kosko's FCM, the connections with plus signs illustrate that an increase in *Islamic Fundamentalism* node causes some degree of increase in *Arab Radicalism*, some degree of increase in *PLO Terrorism*, some degree of decrease in the *Strength of Lebanese Government*, and some degree of decrease in *Soviet Imperialism*. Conversely, the connections with minus signs some degree of decrease in *Islamic Fundamentalism* leads to a decrease, to some degree, of *Arab Radicalism* and *PLO Terrorism*, which causes some degree of increase in the *Strength of Lebanese Government*.

The second example is Kosko's FCM on South African apartheid laws and demonstrates how decision makers ask "what-if" questions of FCMs. In 1986, economist

[26] Ibid.

Walter Williams wrote an article for the San Diego *Union* titled "South Africa Is Changing." In the article, Williams opposed the idea that the United States government should pressure the Botha government to abolish apartheid laws by disinvesting in South Africa. Although disinvesting was the prevalent view and the idea seemed to make sense as a pressure point, Williams argued that disinvesting would lower the standard of living, decrease job opportunities for the poor, and destabilize South Africa.

To test William's ideas, Bart Kosko created a FCM (Figure 11) and used it to evaluate two questions. The first question Kosko evaluated was "What if countries invest in South Africa to a high degree?" To evaluate this question he mathematically "turned on" the FCM's policy node, *Foreign Investment*, and observed the cascading effects. The fuzzy cognitive map settled down with the following nodes turned on: *Foreign Investment, Mining, Black Employment, White Racist Radicalism, Strength of Government,* and *National Party Constituency.* The FCM's nodes representing *Job Reservation Laws* and *Apartheid* turned off. Although a pattern prediction, not a numerical prediction, this particular arrangement supported William's argument that stopping foreign investment to South Africa hurts the very people the United States intended to help. The South African poor would have fewer jobs and a lower standard of living leading to the destabilization of the country. Counter to conventional wisdom of the time, which called disinvestment to pressure South Africa's government to abolish apartheid laws, Kosko's FCM indicated foreign investment is vital for South Africa.[27]

[27] Kosko, *Fuzzy Thinking*, 227-229. In the same chapter, Kosko describes international drug trade, South African apartheid, Islamic fundamentalism, and how bad weather affects driving using fuzzy cognitive maps. This variety of maps further demonstrates the flexibility, adaptability, and utility of fuzzy cognitive maps.

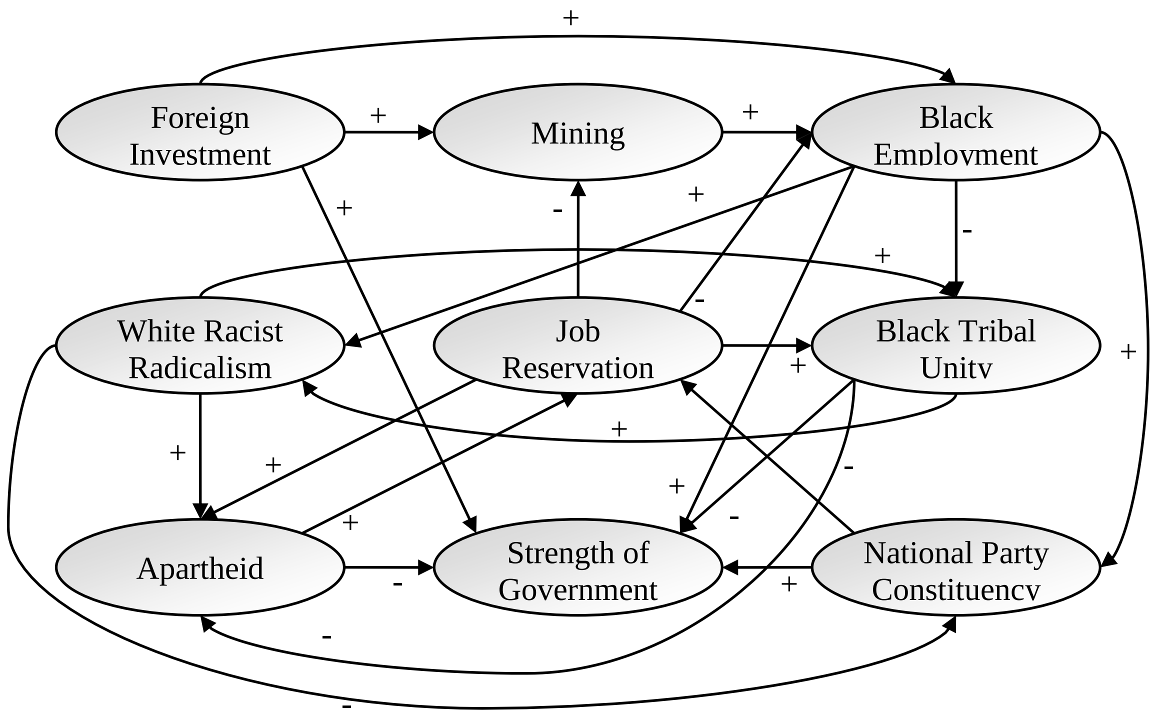

Figure 11. Kosko's South African apartheid fuzzy cognitive map.[28]

The second question Kosko evaluated was "What is the impact of disinvestment in South Africa?" To test this notion, Kosko turned on 100 percent of the FCM's policy node, *Foreign Investment*, and held it on until the FCM reached equilibrium. Then he simulated complete disinvestment by turning off the *Foreign Investment* node. The FCM eventually settled down into an alternating two-state-limit cycle. In the first state, the nodes representing *Job Reservation Laws* and *White Racist Radicalism* remained on. In the second state, the nodes representing *Black Tribal Unity* and *Apartheid* remained on. The FCM alternated between these two states indicating a fallen government, social chaos, and race war.[29] Kosko fuzzy cognitive map outcomes directly support William's

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[28] Ibid., 227.

[29] Kosko, *Fuzzy Thinking*, 227-229.

argument and his conclusions that disinvesting would lower the standard of living, decrease job opportunities for the poor, and destabilize South Africa.

The third example demonstrating FCM's potential as a tool for modeling non-state actor deterrence deals with counterinsurgency in Afghanistan. Nathaniel Fick wrote an opinion piece for the *Washington Post* on August 12, 2007 titled "To defeat the Taliban – fight less, win more." Fick's article discusses four paradoxes of counterinsurgency: first, the best weapons are the ones that do not shoot; second, more force protection may make one less safe; third, using more force may make one less effective; and fourth, tactical success does not guarantee strategic victory. Fick encapsulates his counterinsurgency model with the phrase it is the "kind of war you win by not shooting."[30]

Myriam Abramson, a computer scientist for the Naval Research Laboratory in Washington D.C., created a counterinsurgency fuzzy cognitive map from Fick's article (Figure 12). She drew concept nodes and added lines with various weightings to designate causal relationships between nodes. In Figure 12, the concept nodes *Infrastructure, Insurgency, Strength of Government*, *Military Strikes,* and *Force Protection* best express key components of Fick's counterinsurgency paradoxes. After completing her counterinsurgency FCM, Abramson set out to validate Fick's counterinsurgency paradoxes.

[30] Nathaniel Fick, "To defeat the Taliban – fight less, win more," *Washington Post,* August 12, 2007.

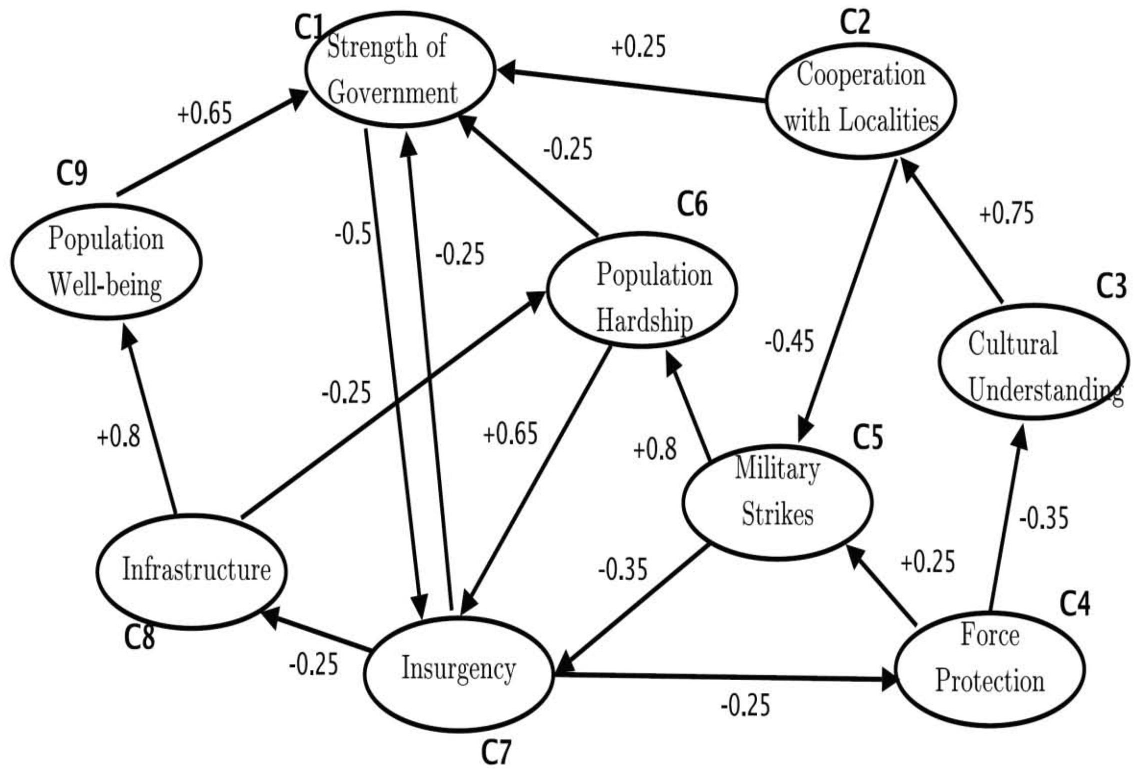

Figure 12. Abramson's counterinsurgency fuzzy cognitive map.[31]

Abramson first asked the question "Does increased *Force Protection* cause an increase in *Insurgency*?" To ask the question, she continually increased the *Force Protection* node and observed the affect throughout the counterinsurgency FCM. Her results supported Fick's claims and showed that increasing *Force Protection* resulted in an increase in *Insurgency* with an associated decrease in government legitimacy represented by the *Strength of Government* node.

Abramson next asked the question "Does building up *Infrastructure* decrease *Insurgency*?" To assess this question, Abramson increased the *Infrastructure* concept node and analyzed the results. Her FCM showed significant increase in *Strength of*

[31] Myriam Abramson, "Causal Emergence of "Soft" Events" (paper presented at the fall symposium series for the Association for the Advancement of Artificial Intelligence, Arlington, Virginia, November 9-11, 2007).

Government (approximately a fourfold increase) with slight decreases in the *Insurgency* concept node. This result suggests focusing on building infrastructure while providing a big boost to the *Strength of Government* node is not the only solution.

Finally, Abramson asked "What if *Infrastructure* and *Force Protection* are increased?" Abramson asserts, "The results show the paradox described in the article, namely, how insurgency increases with an increase in Force Protection without establishing legitimacy for the government. Combining *Force Protection* with increased *Infrastructure* (C4 + C8) produces the best results according to this cognitive map."[32] Her FCM showed higher increase in *Strength of Government* than just *Infrastructure* improvements provided with an almost double decrease in the *Insurgency* concept node. This result suggests the best approach to decreasing *Insurgency* is improving *Infrastructure* and *Force Protection*.

The previous examples demonstrated the flexibility, adaptability, and utility fuzzy cognitive maps contribute to understanding strategic decision-making environments. All three examples demonstrate FCMs can be applied to modeling non-state actor deterrence. According to their creator, Bart Kosko,

> It [FCM] lets everyone pack her own wisdom and nonsense into a math picture of some piece of the world. But once packed in, the FCM predicts outcomes and we can compare these with data to test them. The outcome of large FCMs may surprise you. The best most of us can do is argue about single arrows. We do less well when we try to reason with a large set of connected concepts. FCMs help us see the big picture and do something with it.[33]

Because FCMs allow for the drawing of causal pictures or diagrams, they tie together facts, things, and processes to policies, values, and objectives. Fuzzy cognitive maps

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[32] Abramson, "Causal Emergence."

[33] Kosko, *Fuzzy Thinking*, 224-225.

allow for the prediction of how complex events interact and play out.[34] They are extremely flexible and their nodes can represent events, actions, goals, values, or other fuzzy cognitive maps.[35] All the while, fuzzy cognitive maps highlight the vagueness and uncertainty that is crucial in human interactions.

[34] Ibid., 222.

[35] Dickerson and Kosko, “Virtual Worlds,” 174-175.

CONCLUSION

Charles C. Ragin stated in *Fuzzy-Set Social Science*, "Fuzzy sets have the potential to transform research that is oriented toward 'discovery,' toward gaining new insights about the world."[1] This monograph demonstrated fuzzy logic's potential toward gaining new insights to provide flexible and adaptable models as well as valuable insights for deterring non-state actors. Communication using words, images, and deeds underpins all deterrence and human perception in strategic communication is inherently imprecise and vague. By their very nature, fuzzy logic concepts provide a means of dealing with vague and approximate perceptions that are not precisely fixed. Because, as Ragin notes, "in many practical applications, cooperation and non-cooperation are not matters of 'All or Nothing' …decision makers do not always face a stark choice between total cooperation and total non-cooperation."[2] This monograph traced the fuzzy logic themes of flexibility and adaptability demonstrating their application through fuzzy cognitive maps to non-state actor deterrence.

Deterrence is strategic decision-making process grounded in the assumed rationality of individuals and groups who are pragmatic, flexible, and seek to minimize risks of serious consequences.[3] The heart of deterrence is manipulating behavior by clearly communicating the threat of harm to adversaries. Deterrence rests on the assumption that pragmatism and rationality exist in the decision-making model of both the nation-state and non-state actor. Today's strategic environment represents a shift

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[1] Ragin, *Fuzzy-Set Social Science*, 4.

[2] Raman, *Fuzzy Resolution Prisoner's Dilemma*, 12.

[3] Morgan, *Deterrence: A Conceptual Analysis*, 15-16.

from the Cold War's focus on major player nuclear deterrence and requires a new approach to strategic decision making. While traditional deterrence models still hold true for nation-state actors, it is less useful for non-state threats. A new approach is needed that accounts for the complexity and ambiguity presented in non-state actor deterrence. Fuzzy logic provides that approach.

Fuzzy logic, rooted in the ideas of British philosopher and logician Bertrand Russell, specializes in handling uncertainty, shades of truth, vagueness, and ambiguity. These characteristics, like the ability to represent the vagueness and imprecision of human language, are extremely useful for modeling non-state actor deterrence. When, combined with fuzzy logic's ability to expand decision space beyond all-or-nothing approaches, the ability to represent vagueness and ambiguity enable a more accurate model of the complex environment swirling around the strategic deterrence decision maker. Allowance for degree and ambiguity are key terms in describing the non-state actor deterrence environment. Fuzzy logic tools open up and describe this environment in a rich and real world way that a strict binary logic approaches cannot duplicate.

Fuzzy logic concepts were applied to a traditional deterrence game, the Prisoner's Dilemma, successfully demonstrating complexities and possibilities that were not evident when utilizing a crisp Boolean logic approach. Unlike the binary method, the fuzzy logic approach supports the concept of a decision that is both partially cooperative and partially aggressive. This approach is superior to binary representations in many ways. The fuzzy Prisoner's Dilemma is more flexible and representative of real world human interactions, whether nation-state versus nation-state or nation-state versus non-state actor. Using a fuzzy framework, cooperation is a matter of degrees that provides decision makers more

policy and action space rather than an all-or-nothing choice. The fuzzy logic Prisoner's Dilemma illustrated a richer view of strategic decision space – the world presented in color (or at least gray-scale) rather than two-dimensional black and white choices.

Extending the non-state actor deterrence toolset to include fuzzy cognitive maps provided several tools for decision makers. First, fuzzy cognitive maps (FCMs) draw causal pictures or diagrams of complex systems by tying facts, things, and processes together with policies, values, and objectives. FCMs are simple, flexible, and powerful tools enabling decision makers to analyze and model the real world. Second, FCMs are dynamic systems that feed on vague, uncertain, and unreliable information. Third, using FCMs as decision-making support tools improves understanding and comprehension. Finally, FCMs are generally quick and easy to acquire from multiple knowledge sources with varying degrees of expertise and experience. Each of these FCMs represents a worldview, which can be combined into one FCM. Because FCMs allow for the drawing of causal pictures or diagrams, they tie together facts, things, and processes to policies, values, and objectives. Fuzzy cognitive maps allow for the prediction of how complex events interact and play out. All the while, fuzzy cognitive maps by the virtue of being fuzzy and not crisp allow for vagueness and uncertainty that is a given in human interactions.

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